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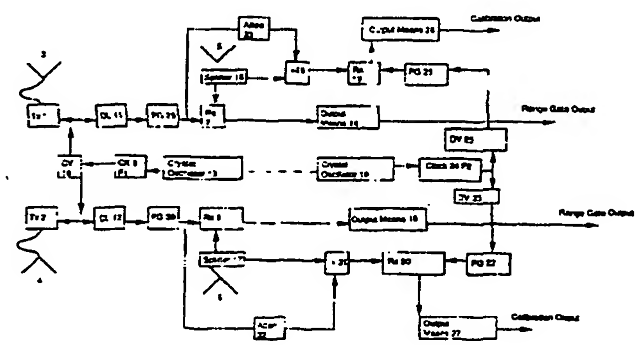

**(57) Abstract**

Apparatus for determining a displacement characteristic of an object comprises means (Tx1, Tx2, 3, 4) for transmitting, at a given transmission time, a probe signal towards the object; means (5, 6) for receiving the probe signal returned by the object; means (DL11, DL12, PG28, PG30) for generating a detection timing signal at a delay after the transmission time, corresponding to a selected range for the object; first detecting means (Rx7, Rx8), coupled to the receiving means and responsive to the timing signal, for detecting the returned probe signal occurring at the delay of the timing signal; and second detecting means (Rx19, Rx20) for detecting the relative timing of the detection timing signal and of a signal having a predetermined timing with respect to the transmission time; whereby a measure of the range of the object can be determined from the relative timing of these two signals, from which range measure the object displacement characteristic can be determined. Apparatus for transmitting and receiving data is also disclosed, as further is apparatus for assessing the approach of an object to a specified location. Analogous methods are also disclosed.

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# APPARATUS AND METHOD FOR DISPLACEMENT DETERMINATION, DATA TRANSFER AND ASSESSMENT.

The present invention relates generally to apparatus for and a method of determining a displacement characteristic of an object. It also relates to apparatus for and methods of transmitting and receiving data. Finally, it relates to apparatus for and a method of assessing the approach of an object to a specified point.

More particularly, the invention relates to a scoring system of the type which can provide a score for the proximity of approach of an object such as a missile or intruder to a specified location such as a target aircraft or other detection location. Although the invention is described in detail with reference to a radar system, it would also function successfully using, for example, infra-red or acoustic techniques.

In numerous applications a ranging radar system is conventionally used to derive measurements of range to one or more targets. In some of these applications, the accuracy of such range measurements is a principal requirement. Examples may be found in missile scoring radars, collision avoidance and intruder detection. A common situation is where a radar sensor is connected to a processor at a ground station via a narrow bandwidth telemetry link, and where the sensor must detect the target with high reliability at near real-time rate.

An extreme example, which will be used to describe the preferred features of the present invention, is that of a precision terminal trajectory scoring radar system in which the differences between range measurements to an object, from transceivers separated only by short baselines, are

used to determine accurately its angular position, and hence provide a proximity score.

In a conventional radar system, the range of the object is determined by repeatedly transmitting a radio-frequency probe pulse from a transmission means, and receiving this at a receiving means. The probe pulse travels both directly to the receiving means and also indirectly by way of reflection from the object. A detecting means detects all such signals received by the receiving means, and determines the range of the object from the timing delay of the reflected pulse relative to the directly received pulse (the "direct" pulse). The range is then simply the relative delay divided by the speed of light. Such a radar system is described, for example, in a book by Skolnik, M. I. entitled "Introduction to Radar Systems", McGraw-Hill, 1962.

In the conventional radar system, the detecting means samples the signals received by the receiving means at a sampling frequency very significantly less than the repetition frequency of the probe pulse. This is unavoidable because of various hardware restrictions in the system.

The conventional system suffers from two disadvantages of relevance to the present invention. Firstly, because of the relatively low sampling frequency, the system cannot cope with fast data rates such as might be encountered in assessing the approach of a hypersonic missile or the like. Secondly, the system suffers from what may be termed a "dynamic range" problem. The detecting means detects a signal which comprises, on the same magnitude scale, both the direct pulse and also the reflected pulse. If the reflected pulse is very much smaller in magnitude than the direct pulse, which is frequently the case in systems for the detection of small missiles and like small objects,

then the detecting means may have great difficulty in accurately detecting both signals, due to their wide dynamic range.

A missile scoring radar system is known from International Patent Application No. PCT/GB90/00602, which names Cambridge Consultants Limited as patent applicant, and whose disclosure is incorporated herein by reference.

In this document is disclosed a missile scoring system based on an impulse radar technique where the missile is sensed as it crosses a sequence of precision range gates (or "regions"). From the crossing sequence of the range regions the displacement characteristics of the missile, such as its trajectory and attitude, can be determined. The precision range gating is such that it is possible to measure accurately the time at which a feature of the approaching missile, such as its nose or tail fins, coincides with the range of the range region. Since the range of the region and the time of coincidence are known, they can be used as data from which the position of the missile and its trajectory may be calculated. The accuracy of the time and range measurements determines that of the final trajectory reconstruction. Analogous processes could be used in other ranging systems.

In the context of the present invention there are three important features of this known system.

Firstly, in order to determine the range of the object, a detection timing signal is generated at a delay after the time at which the radar probe pulse is transmitted (the transmission time), so as to a detect the object when it is at a particular range region. That portion of the probe signal reflected from the object which occurs at the delay of the timing signal is then detected, and is used to assess the presence or absence of the object at any

particular time. A measure of the range of the range region, and hence the object (if present), is then determined from the delay of the timing signal.

Whilst this feature has been found to perform well in practice, it suffers from a limitation concerning the manner in which the range of the range regions is calibrated. Calibration is necessary, because in the known scoring radar system no absolute determination of range is made whilst the system is in operation; the delay of the timing signal needs to be pre-calibrated since it is not measured with reference to any feature of the radar signal having a known timing. This is in contrast to the conventional radar system described previously above, where range is determined directly from the time delay between the reflected pulse and the direct pulse.

In the known scoring radar system, the range of the range regions is in fact pre-calibrated manually at the manufacture stage by positioning a reflective sphere at the various range regions. This procedure can, however, be both cumbersome and inaccurate. Furthermore, pursuant to the present invention, it has now been found that this procedure is disadvantageous, in so far as the calibration cannot be updated during actual operation of the system. It has been found that the initial manual calibration may drift appreciably due to temperature, ageing and like effects in the components of the system. The effect of such drift is to introduce inaccuracies into the range determination.

Aside from careful manual pre-calibration, and the use of crystal oscillators and high-speed logic to determine the range region positions, no further special provision is made in this known system to achieve a high level of accuracy for the range measurements. This has been found to be adequate when such a system is used on a full-scale

target aircraft; however, for use on small subscale targets (perhaps, for example, aircraft with a wing-span of as little as 1 metre), greater accuracy may be needed to compensate for the smaller baselines offered by such targets. With smaller baselines/nose to tail dimensions, accuracy degrades, since, amongst other things, it becomes more difficult to determine accurately the entry angle of the missile.

The present invention therefore seeks to provide a means of accurately calibrating such a radar system, using such range regions. It also seeks to monitor changes in its function, since it is important to ascertain the health of the system.

A second significant feature of the known scoring radar system is the high rate at which data needs to be transferred from the target aircraft to the receiving ground station where the data is processed in detail. In fact, the known system requires a data transmission telemetry bandwidth which is sufficiently wide to preclude its use in many potential applications.

The third and final significant feature of the known system is the manner in which the approach of the missile is assessed. In this known system, the detecting means monitors at a high data rate a region awaiting the occurrence of an event (in this case the arrival of a missile). In practice, the raw data rate from the detecting means is high (5-20 Mbit/s) and the final data processing is complex. Thus it is necessary to identify the occurrence of events with a low bandwidth process to avoid overloading the complex processor with spurious events. With this known system, this has been achieved as follows.

As explained already, multiple range regions are employed to detect the missile when it flies close to the target.

When the missile is detected in a range region, it is assumed that larger energy per unit time would be observed than when only background noise is detected. Therefore, the engagement is identified by summing the detections at all of the channels (that is, at all the range regions and for all of the plurality of receivers which are used). An engagement is scored if the sum is above a given threshold.

Unfortunately, the above procedure has been found to be insufficiently robust to practical noise mechanisms. In particular, in the event of an external interfering transmission being received, then typically all the channels would detect high signals simultaneously. Also, in the event of clutter being received due to reflections of the radar transmit signal around the aircraft (multi-path reflections), again simultaneous events unconnected with the approach of the missile would be observed at multiple range regions.

In its various aspects, the present invention seeks, amongst other things, to provide enhancements to the performance of a range measuring/scoring radar system using impulse radar techniques.

In overview, these aspects relate to the following enhancements.

In one aspect of the present invention, preferably a real-time auto-calibration system is provided which can continuously measure the range of the range regions and hence take out any drift in the system calibration due to temperature, ageing or like effects.

Secondly, there are requirements where the telemetry link from the target aircraft to the ground station is of limited bandwidth and the data hence has to be compressed. Hence in a second aspect there is preferably provided a

data compression technique which can reduce the data by a factor of four while maintaining high fidelity and minimum latency. In this context, "latency" refers to the delay between the generation of the data and its transmission. Minimum latency is particularly important in situations such as where the target aircraft might be destroyed and hence data transmission could end prematurely.

Thirdly, there are requirements where it is necessary to produce a near real-time engagement score. Thus in a third aspect there is preferably provided an algorithm which can enable the missile detection data to be analysed at real-time rate using practical computer hardware.

Hence, in one aspect of the present invention, there is provided apparatus for determining a displacement characteristic of an object, comprising means for transmitting, at a given transmission time, a probe signal towards the object; means for receiving the probe signal returned by the object; means for generating a detection timing signal at a delay after the transmission time, corresponding to a selected range for the object; first detecting means, coupled to the receiving means and responsive to the timing signal, for detecting the returned probe signal occurring at the delay of the timing signal; and second detecting means for detecting the relative timing of the detection timing signal and of a signal having a predetermined timing with respect to the transmission time; whereby the object displacement characteristic can be determined from the relative timing of these two signals.

The object displacement characteristic may, for example, be its range from a specified location or its velocity.

In so far as the apparatus of the present invention includes a first detecting means to detect (only) the probe

signal occurring at the delay of the timing signal, it shares the two advantages of the system disclosed in PCT/GB90/00602 of being able to cope with rapid movements of the object and of being able to cope with return signals of low strength compared to the strength of the direct signal.

However, unlike the known system, a second detecting means is provided for detecting the relative timing of the detection timing signal and of a signal having a predetermined timing with respect to the transmission time, from which relative timing information a measure of the selected range (and hence the object displacement characteristic) can be determined. Hence the apparatus of the present invention can "auto-calibrate", that is, it can without manual calibration determine the selected range corresponding to the detection timing signal; the apparatus can also do this on a constantly updated basis. This can avoid the need for an initial manual calibration and can reduce (or even eliminate) problems due to drift in the calibration on account of temperature, ageing or other like effects.

A further advantage which stems from the above is that, since calibration drift problems can be reduced or eliminated, cheaper components can be used, even though such components may be prone to significant temperature or ageing effects. Hence the cost of the apparatus can be reduced significantly.

Preferably, the transmitting means is adapted to transmit the probe signal at regularly repeated transmission times, at a given repetition frequency, and the second detecting means is adapted to sample the signal of predetermined timing at a sampling frequency lower than the repetition frequency. By arranging that the sampling frequency is lower than the repetition frequency, the apparatus of the

present invention need not be limited as to the speed of object it can detect by the rate at which the calibration process takes place. It has been found that in practice, due to hardware restrictions, the calibration process cannot easily be operated at the same rate at which it would typically be desirable to operate the repetition frequency. Further, it has been found that it is not even desirable to operate the calibration process at such a rate, since the calibration would typically not need to be updated particularly frequently. An update rate of once every few seconds or even minutes might typically be acceptable.

Preferably, the sampling frequency is much less than the repetition frequency, more preferably less than 100 millionths of the repetition frequency, even more preferably less than 20 or even 5 millionths. In the preferred embodiment it is one millionth or less. Lower ratios still would be desirable but are not easily achieved in practice. By operating at such a low relative frequency, the requirements on the apparatus in terms of the storage and transmission of data can be very significantly reduced.

Preferably, the apparatus includes two oscillators for timing the operation of the transmitting and second detecting means so that the repetition frequency is timed by one oscillator and the sampling frequency is timed by the beat frequency between the two oscillators. This is a particularly simple and effective way of putting the invention into practice.

Preferably, the transmitting means is adapted to transmit the probe signal not only to the object but also via a path of fixed length, which does not include the object, through the ambient medium to the receiving means, and the second detecting means is adapted to detect the fixed path length signal as the signal having a predetermined timing with

respect to the transmission time. By detecting the timing of the detection timing signal relative to that of the fixed path length signal (the "direct" signal), the calibration afforded by the present invention can be particularly accurate. The "predetermined timing" of the direct signal with respect to the transmission time is simply the length of the path of fixed length (that is, typically the direct distance between the transmitting and receiving antennae or else possibly the distance between the two antennae via a third point such as a reflector), divided by the speed of light. This distance can be predetermined to a high degree of accuracy.

In an alternative preferred embodiment, the probe signal or a transmit trigger signal might, for example, b transmitted along a very high quality cable of known length and good temperature and ageing properties to the receiving means, as the signal having a predetermined timing with respect to the transmission time. In this case the predetermined timing delay of the signal as received by the receiving means would be dependent at least in part on the length of the cable.

Preferably, the apparatus includes splitter means for splitting the signal received by the receiving means to both the first and the second detecting means. In the preferred embodiment, this signal would include not only the returned probe signal but also the direct signal. This is a particularly simple way of putting the invention into effect.

Preferably, the apparatus includes means for combining the signal having a predetermined timing and the detection timing signal, and for passing the combined signal to the second detecting means.

Preferably, the apparatus includes means for producing a

signal representative of the status of the apparatus in dependence on the output of the second detecting means. This feature is of particular benefit, since, unlike the output from the first detecting means, the output from the second detecting means, containing as it does information concerning the timing of the transmission of the probe signal, can provide useful status information, such as (perhaps most importantly) whether the transmitting means is actually functioning correctly. In the context of missile tests, status information is particularly important in view of the high costs involved in the tests. Very often the tests can result in the destruction of the target aircraft. If the apparatus of the present invention were not functioning properly during such a test, the test would usually have to be repeated, at great expense.

Preferably, if the generating means is adapted to generate a plurality of detection timing signals (corresponding to a plurality of range regions), the second detecting means is adapted to detect the timing of each of the detection timing signals relative to the signal having a predetermined timing. This can reduce the amount of calibration data produced.

Preferably, the apparatus includes means for determining a measure of the selected range from the relative timing of the signal having a predetermined timing and the detection timing signal.

The invention extends to a method of determining a displacement characteristic of an object, comprising transmitting, at a given transmission time, a probe signal towards the object; receiving the probe signal returned by the object; generating a detection timing signal at a delay after the transmission time, corresponding to a selected range for the object; a first detecting step wherein the returned probe signal occurring at the delay of the timing

signal is detected; and a second detecting step wherein the relative timing of the detection timing signal and of a signal having a predetermined timing with respect to the transmission time is detected; whereby the object displacement characteristic can be determined from the relative timing of these two signals.

Analogous method steps to the above described apparatus features are also provided within the scope of the present invention.

In a second aspect, the present invention provides apparatus for transmitting data. A form of such apparatus is known, in which input means is provided for receiving a data stream comprising a plurality of data samples, and a data value (such as a single data bit) characteristic of each data sample is evaluated. The data value represents a "compressed" form of the data stream. Compression permits transmission of the data at a higher rate or over a narrower telemetry bandwidth.

The known apparatus has the disadvantage that the compressed data values can lag or lead the actual data stream quite significantly in time, especially in circumstances where the data samples are altering rapidly in value.

The present invention seeks to solve this problem.

In a second aspect of the present invention, there is provided apparatus for transmitting data, comprising input means for receiving a plurality of data samples; means for evaluating a respective block data value characteristic of each of a plurality of data blocks, each data block comprising a plurality of data samples; and means for transmitting the respective data value for each block.

By arranging the data samples in blocks and transmitting, for each block, a data value characteristic of that block, it has been discovered pursuant to the present invention that the problem of time lag or lead encountered in the known data transmission apparatus can largely be obviated. The reason for this is that the apparatus of the present invention has a longer time (related to the block length) over which it can react to changes in the data (especially sharp rises or falls).

Each data block may typically comprise a plurality of time-sequential data samples.

Preferably, the evaluating means is adapted to evaluate individual data values representative of particular data samples in each block, and the transmitting means is adapted to transmit said individual values. By evaluating individual data values representative of some or all of the individual data samples and transmitting these, the accuracy of the technique can be improved still further.

More preferably, the evaluating means is adapted to evaluate the block and individual data values respectively as an exponent which is constant for each block and a plurality of mantissas which are variable within each block. This is a particularly effective way of putting the invention into practice. It can allow for significant variation in overall magnitude between individual blocks, whilst also allowing a fair degree of variation actually within these blocks.

Preferably, the evaluating means is adapted to evaluate the individual data values as taking as possible values the value zero as well as at least one other value. This arrangement can allow data transfer of greater accuracy, especially in situations where the stream of data samples remains at a largely constant level over a substantial

period of time.

Preferably, the evaluating means is adapted to evaluate the individual data values as taking one of an odd number of possible values. This is especially preferred if one of the possible values is zero, so that the compressed representations of the data samples can be symmetrical about a central zero value.

Preferably, the transmitting means is adapted to transmit the individual data values as *n* bit words, each word representing *m* individual data values, the number of possible values for the individual data values taken to the power *m* being no less than 25 % lower than, preferably no less than 10 % lower than, and no greater than, two taken to the nearest power of *n*. This can ensure that the data transfer takes place at a fast and efficient rate, by arranging that each transmitted word is as fully packed with data as possible.

In the preferred embodiment, *m* is 3, and said number of possible values is either 3 or 5. In this event, *n* would be either 5 or 7, so that two to the power *n* would be either 32 or 128; the number of possible values taken to the power *m* would be either 27 or 125.

Preferably, the evaluating means is adapted to evaluate the individual data values in dependence on the difference between data samples. By this feature, the effect of any d.c. offset in the data stream can be removed. If this feature is provided, the transmitting means may be adapted to transmit at least one further data value characteristic of the absolute value of a given data sample or samples. This latter feature can reduce the problems caused by fade occurring in the data transmission, by providing an absolute value from which the receiving apparatus can recover the data stream.

The invention extends to apparatus for receiving data, comprising means for receiving the data in the form of a plurality of block data values, each block data value being characteristic of a respective data block, the block comprising a plurality of data samples; means for evaluating the data samples in dependence on the block data values; and means for outputting the data samples.

Preferably, the receiving means is adapted to receive individual data values representative of particular data samples in each block, and the evaluating means is adapted to evaluate the data samples in further dependence on the individual data values.

Preferably, the evaluating means is adapted to evaluate the data samples in dependence on block and individual data values which are respectively an exponent which is constant for each block and a plurality of mantissas which are variable within each block.

Preferably, the evaluating means is adapted to evaluate the data samples in dependence on individual data values which take as possible values the value zero as well as at least one other value.

Preferably, the evaluating means is adapted to evaluate the data samples in dependence on individual data values which take one of an odd number of possible values.

Preferably, the receiving means is adapted to receive data as *n* bit words, each word representing *m* individual data values, the number of possible values for the individual values taken to the power *m* being no less than 25 % lower than, preferably no less than 10 % lower than, and no greater than, two taken to the nearest power of *n*, and is further adapted to convert each received word into the *m* individual data values.

Preferably, the evaluating means is adapted to evaluate the data samples on the basis that the individual data values have been evaluated in dependence on the difference between data samples.

Preferably, the receiving means is adapted to receive at least one further data value characteristic of the absolute value of a given data sample or samples.

The invention also extends to data transfer apparatus comprising data transmitting and data receiving apparatus as aforesaid.

The invention further extends to a method of transmitting data, comprising receiving a plurality of data samples; evaluating a respective block data value characteristic of each of a plurality of data blocks, each data block comprising a plurality of data samples; and transmitting the respective data value for each block.

The invention further extends to a method of receiving data, comprising receiving the data in the form of a plurality of block data values, each block data value being characteristic of a respective data block, the block comprising a plurality of data samples; evaluating the data samples in dependence on the block data values; and outputting the data samples.

Method steps analogous to the above described apparatus features are also provided within the scope of the present invention.

In a third aspect of the present invention, there is provided apparatus for assessing the approach of an object to a specified location, comprising means for detecting the likely presence of the object in a plurality of range regions at specified ranges from said location, and for

producing a detection signal for each range region in which the likely presence of the object is detected; means for determining (preferably independently) a measure of the velocity of the object; and means for assessing the approach of the object in dependence on whether the velocity measure is consistent with the evolution pattern of the detection signals.

By determining a measure of the velocity of the object and assessing the approach of the object in dependence on whether the velocity measure is consistent with the evolution pattern of the detection signals, the apparatus of the present invention can assess the approach of an object with a lower false alarm rate than is possible with the system known from International Patent Application No. PCT/GB90/00602. The velocity measure can effectively provide a way of verifying the presence of the object, even in the presence of a substantial amount of noise.

In fact, this aspect of the invention is likely to be sufficiently reliable in practice that it can provide a fully automatic assessment, without the need for manual intervention (as is required with the known system).

Another advantage of the apparatus of the present invention is that, as described in detail later, it can operate virtually in real-time. This may be important, say, if multiple missile firings are taking place, so that the results of one firing can be assessed before another missile is fired.

The assessment of the approach of the object may, for example, and most importantly, include an assessment of whether the detection signals actually do represent the approach of the object, or whether they represent some noise phenomenon or the like. The assessment may also include a determination of the closest proximity of the

object to the location.

Means may be provided for producing an assessment signal in dependence on the output of the assessing means.

Preferably, the determining means is adapted to determine the velocity measure by sensing the velocity of the object in a plurality of velocity bands. This can provide an apparatus of great versatility, in that it can cope simply and efficiently with a wide range of velocities.

The detecting means may be adapted to produce detection signals for each velocity band, and means may be provided for adjusting the evolution patterns for the velocity bands so that they are substantially independent of velocity. This feature can afford a particularly efficient way of assessing the approach of the object, since the evolution patterns can then be matched against a single acceptable pattern or set of patterns, substantially independent of velocity. The adjusting means may, for example, operate by effecting some form of "downsampling" on the detection signals produced for the different velocity bands.

Preferably, the determining means is such that the velocity bands overlap one another. By this feature, even if the perceived velocity of the object varies somewhat (which is likely as it moves past the specified location), it can nevertheless be assured that the velocity variation of the object can be accommodated within one such band.

Preferably, the detecting means is adapted to detect the likely presence of the object separately at each velocity band, and the assessing means is adapted to assess the approach of the object in dependence separately on the respective evolution pattern of the detection signals at each velocity band. By producing such an approach assessment, the apparatus can produce more reliable

results, and can even assess the approach of multiple objects approaching at different velocities.

Preferably, the assessing means is adapted to assess the approach of the object in dependence on whether the evolution pattern falls between two extremes of allowability. This is a particularly simple way of putting the invention into effect, and can take account of expected relatively minor variations in the evolution pattern from the theoretical "norm".

Preferably, the assessing means is adapted to assess the approach of the object in dependence on whether the evolution pattern approximates to a hyperbolic function. In so far as a hyperbolic function is a physically realistic representation of the evolution pattern (that is, the theoretical "norm") to be expected in the context of a missile scoring radar system, by this feature can be afforded an accurate assessment of the object approach.

Preferably, the detecting means comprises a plurality of individual detecting means, preferably at separate locations, and the assessing means is adapted to assess the approach of the object in dependence on the respective evolution pattern of the detection signals for each individual detecting means. This feature can ensure an even more accurate assessment of the object approach.

Preferably, the apparatus includes means for generating an estimate of background noise, and the detecting means is adapted to produce the detection signal according to whether the detecting means detects the likely presence of the object above a noise threshold which is dependent on the noise estimate. If so, the generating means may be adapted to generate a noise estimate which is time dependent, so that account can be taken of any changes which might occur in the background noise levels.

The noise threshold may be based on a delayed version of the noise estimate. Hence the approach of the object need not incorrectly influence the noise estimate. For the same reason, the noise threshold may be based on a version of the noise estimate averaged over a given duration.

Preferably, the detecting means is adapted to produce the detection signal according to whether the detecting means detects the likely presence of the object above both of two noise thresholds, one of which is based on the sum of the noise estimate and a first constant, the other of which is based on a second constant times the noise estimate. This has been found to be a particularly satisfactory way of putting the invention into practice, since it takes into account the different types of noise likely to be encountered.

The invention extends to a method of assessing the approach of an object to a specified location, comprising detecting the likely presence of the object in a plurality of range regions at specified ranges from said location, and producing a detection signal for each range region in which the likely presence of the object is detected; determining a measure of the velocity of the object; and assessing the approach of the object in dependence on whether the velocity measure is consistent with the evolution pattern of the detection signals.

Method steps analogous to the above described apparatus features are also provided within the scope of the present invention.

Other preferred features of the invention are as follows.

In one aspect, the invention consists in a Vernier time delay calibration method in which two stable oscillators are set at frequencies which differ by a small fraction.

One is used to generate a repetitive waveform with at least one feature at known delay and other features at unknown values of delay (such as in a radar system), whilst the other, at a slightly lower (or possibly higher) frequency, is used to generate a repetitive event whose delay with respect to the known events of the first clock increases regularly from cycle to cycle of the first clock, and by coincidence can be used to measure the delay of unknown events due to the first clock.

Preferably, the second stable oscillator is derived from the first by means of synthesis by a phase-locked loop. Alternatively, the second stable oscillator may be independent of the first. Again, the second stable oscillator may be derived from the first by accurate control of the beat frequency between the two. Yet again, the second stable oscillator is derived from the first by accurate control of the interval between coincidences between events generated by the second clock and the known events generated by the first clock.

Preferably, the "unknown" events are pulses which are simultaneously used to close momentarily sampling switches which themselves create "range gates" in a radar system.

In another aspect, the invention consists in a data compression scheme where the data is compressed using a block floating point scheme where samples are represented by a limited length exponent and a limited length mantissa such that each code represents either the difference between successive samples or the absolute value of a sample.

Preferably, the mantissa is a 5 level code with three such codes packed into a 7 bit word.

In another aspect, the invention consists in a signal

processor where the output of the radar is processed at a discrete number of ranges in a set of frequency bands corresponding to different velocities of the target to achieve detection of targets which have a very wide range of target velocities.

Preferably, the velocity bins are formed using the Fast Fourier Transform and combining the squares of the output of the transform in overlapping frequency bands. Alternatively, the velocity bins could be formed using "wavelet transforms".

Preferably, detection decisions are made on each channel whenever the signal exceeds an absolute threshold or some multiple of the noise in each velocity bin. The detection threshold may be based on a delayed version of the multiple of the noise.

Preferably, the output of the different velocity bins is down-sampled at different rates to make the pattern of detections velocity independent.

Preferably, detection decisions are made only as a result of a sequence of consistent events across multiple channels. Consistency here means that for the velocity under consideration the sequence of ranges measured is consistent with the current velocity.

Preferably, the final detection decision is made according to there being consistent events across multiple receivers. Here "consistent events across multiple receivers" means the same velocity bin at the different receivers at a spacing consistent with the spatial separation of the receivers.

The invention extends to a missile scoring system in which range calibration is provided by a Vernier time delay

calibration method as aforesaid.

The invention also extends to a missile scoring system in which data compression is achieved according to the data compression scheme as aforesaid.

Again, the invention extends to a missile scoring system using velocity selective processing according to the signal processor as aforesaid.

Further, the invention extends to a ranging impulse radar where calibration is achieved using the venier time delay calibration method as aforesaid, where data compression is achieved according to the data compression scheme as aforesaid, or where velocity selective processing is used according to the signal processor as aforesaid.

The various features of the various aspects of the present invention may be combined with one another in any appropriate fashion.

Preferred features of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a known missile scoring radar system;

Figures 2(a), 2(b), 2(c) and 2(d) (prior art) show, respectively, the waveform of a direct wave transmitted by a first transmitter, the waveform of a direct wave transmitted by a second transmitter, and the two switching pulses corresponding to the aforementioned direct waves;

Figure 3 is a block diagram of the scoring radar system of the present invention;

Figure 4 is a block diagram illustrating a data compression apparatus according to the present invention;

Figure 5 is a plot of frequency range against velocity

bin, to illustrate the overlap of the Doppler bands in the present invention;

Figure 6 illustrates the best and worst cases of how a missile radar signature fits within a time window employed in the present invention;

Figure 7 is a plot of radial velocity against scalar miss distance for each of six range gates utilised with the present invention;

Figure 8 is a plot of bistatic range against time;

Figure 9 illustrates two acceptable target evolution patterns;

Figure 10 illustrates first and second points of engagement used in the present invention; and

Figure 11 is a block diagram of a signal processor of the present invention.

Different aspects of the present invention will now be described in the succeeding numbered sections. The description relates specifically to a missile scoring radar system, but it will be understood that the principles adduced can be applied more generally.

## 1. AUTO-CALIBRATION

Referring first to Figure 1, a known scoring radar system comprises essentially two transmitting means Tx1 and Tx2, two transmitting antenna means 3 and 4, two receiving antenna means 5 and 6, two receiving means Rx7 and Rx8 and their associated pulse generators PG28 and PG30, clock means CK9, divider means DV10, two delay means DL11 and DL12, a crystal oscillator 13 for controlling the clock means CK9 at a constant rate F, and two output means 14 and 15 for outputting range gate output.

As used herein, and unless the context otherwise demands, the terms "transmitter" and "receiver" connote the combinations respectively of the transmitting and

transmitting antenna means, and the receiving and receiving antenna means.

The transmitting means Tx1, receiving means Rx7 and output means 14, (together with their associated circuitry), on the one hand, and, on the other hand, the transmitting means Tx2, receiving means Rx8 and output means 15 (together again with their associated circuitry) operate as separate first and second sub-systems. Henceforth, properties relating to the first and second sub-systems are denoted by the subscripts "1" and "2" respectively. The first and second sub-systems are mounted respectively on the upper surface and the lower surface of the target aircraft (not shown), so that coverage of the entire range space around the aircraft is maximised. The relative operational timing of the two sub-systems is determined by the clock CK9, divider means DV10 and delay means DL11 and DL12. The transmitting means Tx1 and Tx2 are adapted to provide short radio-frequency pulses when triggered by the output of the divider means DV10 in the form of transmit trigger pulses. The divider means DV10 serves amongst other things to reduce the frequency of the oscillator 13 output.

Typical radio-frequency pulses are shown in Figures 2(a) and 2(b) for the first and second sub-systems respectively. Such pulses are transmitted from the transmitting means Tx1 and Tx2 via the transmitting antenna means 3 and 4, the ambient medium, and thence to the receiving antenna means 5 and 6 and the two receiving means Rx7 and Rx8. A pulse which is transmitted directly from the transmitter to the receiver antenna means is termed a "direct" wave (or "direct" signal), whilst the transmitted pulse as reflected off a missile is termed a "return signal".

The delay means DL11 and DL12 are arranged to produce detection timing signals in the form of switching pulses

respectively at nominal delay times $\tau_1$ and $\tau_2$ after transmission of the relevant pulse, as shown in Figures 2(c) and 2(d). The delay means are arranged to trigger their respective receiving means Rx7 and Rx8 to act as switches to couple that portion of the return signal occurring when the switching pulses exceed thresholds designated (e) and (f) in Figures 2(c) and 2(d) respectively into the respective output means 14 and 15. In the known scoring radar system, the duration of the switching is approximately 200 picoseconds.

The delays $\tau_1$ and $\tau_2$ at which the return signals are output to the output means 14 and 15 define two range gates (range regions) at fixed ranges from the target aircraft, the range being determined from the delay and from the speed of light ("C"). The range thickness of the range gates is determined from the duration of the switching pulses. The basis of the known scoring radar is to detect the presence of the incoming missile in the particular range gate.

In the known scoring radar system, in reality a large number of range gates are provided by employing for each sub-system a plurality of delay means having different delays (in other words, one receiver and transmitter per several delay means), and by employing more than two sub-systems, each having its own transmitter and receiver. In principle, if the system is to locate the missile precisely in 3-dimensional space, a minimum of four sub-systems would be required. In practice, eight sub-systems are used, four for the lower half of the target aircraft, four for the upper half, so that a detection can be made regardless of whether the missile approaches from below or above the aircraft.

In the known scoring radar system, cabling (for instance between the transmitting means Tx1,Tx2 and the transmitting antenna means 3,4), the electronic transmitting elements

(for instance in the transmitting means), the receiving amplifiers in the receiving means and printed wiring tracks all introduce nominal transmit delays into the two sub-systems, denoted respectively $\delta t_1$ and $\delta t_2$. The delays are due, for example, to charging delays owing to the capacitance of the cabling and the electronic transmitting elements. The delays are subject to small unknown timing errors $\epsilon t_1$ and $\epsilon t_2$, attributable to temperature, ageing and geometric variations and like effects. The pairs of transmitting and receiving antenna means 3, 4, 5, 6 are separated by accurately-known distances $d_1$ and $d_2$, so that the signals arriving at the receiving means Rx7, Rx8, directly from the transmitter means Tx1, Tx2 do so at delays $t_1$ and $t_2$ given by

$$t_1 = \delta t_1 + \epsilon t_1 + d_1/C \quad \text{and} \quad t_2 = \delta t_2 + \epsilon t_2 + d_2/C$$

Likewise, the printed wiring tracks and electronic devices in the receiving means Rx7, Rx8 introduce receive delays $\delta r_1 + \epsilon r_1$ and $\delta r_2 + \epsilon r_2$ into the timing of the detection timing signal. Thus the actual delays of the detection timing signals (switching pulses) are

$$\tau_1 + \delta r_1 + \epsilon r_1, \text{ and } \tau_2 + \delta r_2 + \epsilon r_2$$

The range gates referred to previously are in the form of ellipsoids with foci at the respective transmitting and receiving antenna means 3, 4, 5, 6 such that the sum of the distances from the transmitting antenna means to any point on the surface of the missile and back to the receiving antenna means is equal to R, given, for the first and second sub-systems respectively by:

$$R_1 = C * (\tau_1 + \delta r_1 + \epsilon r_1 - (\delta t_1 + \epsilon t_1)), \text{ and } \quad R_2 = C * (\tau_2 + \delta r_2 + \epsilon r_2 - (\delta t_2 + \epsilon t_2)),$$

where C is the speed of light, as stated above.

In the known system, the values of $R_1$ and $R_2$ are measured by a one-off manual calibration, leading to estimates of ($\delta r_1 - \delta t_1$) and ($\delta r_2 - \delta t_2$). The uncertainty in timing arising from thermal and cable variations and the like is then $\epsilon r_1 - \epsilon t_1$ and $\epsilon r_2 - \epsilon t_2$, and the differential timing uncertainty between the two range gates of the first and second sub-systems is ($\epsilon r_1 - \epsilon r_2 - \epsilon t_1 + \epsilon t_2$).

A preferred embodiment of the present invention is now described with reference to Figure 3. In Figure 3, the same components as are shown in Figure 1 are represented by the same reference numerals. Only those components additional to those described with reference to Figure 1 are now described in detail.

The improvement which is the subject of a preferred aspect of this invention is to introduce a third and fourth receiving means Rx19 and Rx20, splitting means 16 and 17, a further clock means 24, a further crystal oscillator 18, further dividing means DV25 and DV23, further pulse generation means PG21 and PG22, attenuation means 33 and 32, adding means 29 and 31 and further output means 26 and 27. The further clock means 24 is controlled at a rate $F_2$, where $F_2 = F_1 - f$. $F_1$ is the frequency of the clock means CK9, and f is also a constant frequency which may be a small submultiple of F. Usually f will be much smaller than $F_1$. In the preferred embodiment f is 1Hz, whilst $F_1$ is of the order of 2MHz.

As described above in relation to the receiving means Rx7 and Rx8, the further receiving means Rx19 and Rx20 are arranged to receive switching pulses (detection timing signals) from the pulse generation means PG28 and PG30, in this event via the attenuating means 33 and 32 and adding means 29 and 31. The receiving means are arranged to be switched by the further pulse generation means PG21 and PG22 so as to sample at a data rate determined by the

further clock means 24.

In addition to closing the receiving switches in the receiving means Rx7 and Rx8, the pulses (a) and (b) shown in Figure 2 are in parallel used to make precision timing measurements.

In one preferred aspect, the effectiveness of the improvement provided by the present invention resides in the fact that no significant uncertainties in delay occur between the times when each of the signals (c) and (d) in Figure 2 exceed the respective thresholds and the respective times when the switches in the receiving means Rx7 and Rx8 are closed. Any time differences are the result of fixed and well-known propagation delays in short cables or printed wiring within the electronics unit. Thus a measurement of the instant when the respective signals (c) and (d) reach a peak or the centre time of the interval over which they exceed a threshold can be taken as an accurate measurement of the instant when the switches in the receiving means Rx7 and Rx8 are closed. Such a measurement is made in the third and fourth receiving means Rx19 and Rx20. The measurement, if made at intervals of tcal, provides direct measurements of $(\delta r_1 + \epsilon r_1)$ and $(\delta r_2 + \epsilon r_2)$, rather than merely $\delta r_1$ and $\delta r_2$, increasing the accuracy of the range gate calibration, provided that $\delta r_1$ and $\delta r_2$ are stable over the time tcal. The same mechanism can be used to measure the arrival time of the direct transmitted wave at the receiver, giving the values of $(\delta t_1 + \epsilon t_1)$ and $(\delta t_2 + \epsilon t_2)$.

The preferred embodiment of scoring radar system according to the present invention is now explained in more detail with reference to Figure 3. The system can be understood with reference to the top half of Figure 3 because the bottom half is merely another channel disclosing a second transmission to be calibrated for a multistatic system.

The transmitter Tx1 pulses regularly in response to trigger pulses from the clock means CK9 and dividing means DV10. The trigger pulse is delayed by the delay means DL11 and triggers the pulse generator PG28 to produce a switching pulse (detection timing signal) at the delay defining the range gate position. A small fraction (perhaps 1/1000th) of the switching pulse defining the delay of the switching range gate is fed into the adding means 29 which combines a small fraction of the signal from the splitting means 16 and passes this to the third receiving means Rx19 which is clocked at a small offset frequency to the master clock $F_1$. Thus the third receiving means will output a signal to the calibration output means 26 which contains the direct signal transmitted directly between the transmitting and receiving antenna means 3 and 5 and the detection timing signal corresponding to the given range gate. Hence the calibration of the range gate can be derived from the time delay between the direct signal and the detection timing signal.

Because the switches in the third and fourth receiving means Rx19 and Rx20 are repeatedly closed at a constant rate $F_2$, slightly less than $F_1$, the trigger time of these receiving means will slip with respect to the trigger time of the fixed delay receiving means Rx7 and Rx8. The switches in the former receiving means can be regarded as samplers, with their outputs connected to the output means 26 and 27. As this delay (that is, timing slip) increases, at one instant the sampling pulse of the receiving means Rx19 will coincide with the direct wave (a) (see Figure 2); then some time later ("tcgate") it will co-incide with the detection timing signal (c), and then at a time ("tcal") after its coincidence with the direct wave it will co-incide again with the direct wave. If the output means 26 and 27 take the form of low-pass filters, the signal observed there will be the sum of (a) and (c) in Figure 2. Provided that the difference frequency f is constant over

the interval tcal, the range gate delays ($R_1/C$) and ($R_2/C$) may be measured accurately, provided also that $d_1$ and $d_2$ are known equally accurately. Under these circumstances,

$$\frac{R_1/C - d_1/C}{1/f} = tcgate/tcal$$

The analogous expression applies to the lower sub-system ("2").

Note that in this expression the values $\delta t_1$, $\delta t_2$, $\delta r_1$, $\delta r_2$, $\epsilon t_1$, $\epsilon t_2$, $\epsilon r_1$ and $\epsilon r_2$ do not appear; for a given tcgate the value of $R_1$ depends only on the accuracy of $d_1$, which can be measured with a tolerance of millimetres, and f, which is crystal-controlled.

This expression is precise provided that both $F_2$ and $F_1$ (and hence f) are constant over the period tcal, and yields precise, absolute calibration for the two range gates described.

A differential calibration can also be obtained by calculating the difference between the range values $R_1$ and $R_2$ for physically close sub-systems respectively on the upper and lower surfaces of the target aircraft. This is given by

$$\frac{(R_1 - R_2)/C - (d_1 - d_2)/C}{1/f} = \frac{\delta t_{ct} - \delta t_{cr}}{tcal}$$

In this equation, $\delta t_{ct}$ is the difference between the arrival times of the direct waves from the upper and lower sub-systems (as detected by the third and fourth receiving means Rx19 and Rx20), and $\delta t_{cr}$ is the time difference between the detection timing pulses for the upper and lower sub-systems. For this differential calibration to be

accurate, the stability of the difference frequency f is only important over the shorter time $\delta t_{ct}$ minus $\delta t_{cr}$. This differential calibration of the range gates may be particularly useful in circumstances where the transceivers on the upper and lower sub-systems are quite close, and hence the scoring radar system is quite sensitive to the relative positions of the range gates for the two sub-systems. In such a circumstance the standard calibration technique might be employed to calibrate the range for a range gate on one of the sub-systems, and the differential calibration technique might be employed to calibrate the range for the corresponding range gate on the other of the sub-systems.

The calibration technique described above may be termed a Vernier time delay calibration, and in the example is designed to provide delay calibration accurate to a few tens of picoseconds.

In practice, the calibration output from the output means 26 and 27 (Figure 3) is sent to the ground station as a separate output from the range gate output from the output means 14 and 15. The calibration of the system is updated roughly once every eight seconds, which is the rate at which information from all eight receivers is sampled. The system is calibrated according to either the last calibration signal or an average of the last few calibration signals.

Alternatively, the calibration output may be processed on the target aircraft. However, since the calibration output may contain useful information about the status of the system, processing is preferably carried out in the ground station.

In practice, the calibration output from the system is low-pass filtered and then digitised, say, at a rate of 5kHz.

Sampling could be at a lower rate still if desired.

As described above, the calibration is carried out by circuits forming an integral part of the scoring radar system. These allow continuous calibration to be carried out with a repeat cycle of 1/f. However, the calibration could alternatively be carried out using separate calibration equipment, whenever convenient. In this latter alternative, compensation could not be made for thermal and like effects between calibrations.

In the preferred embodiment, it is important to ensure that there is no cross-coupling between the receiving means Rx19 and Rx20 (and their associated circuitry) and the receiving means Rx7 and Rx8 (and their associated circuitry). Such cross-coupling might otherwise interfere with the signals detected by the two sets of receiving means. Cross-coupling can be reduced by ensuring that the number of possible conducted or radiated communication paths is kept to a minimum.

In the most preferred embodiment, there are in total actually 8 detection receiving means (such as Rx7 and Rx8) provided on the target aircraft. For each of these receiving means, there are, further, six separate delay means (corresponding to six range gates), so that each receiving means receives signals from the six separate delay means. Hence, there are 48 channels of range gate data altogether.

For each detection receiving means such as Rx7 and Rx8, there is one calibration receiving means such as Rx19 and Rx20, with the detection timing signals of each of the six delay means being passed to the single calibration receiving means. Hence there are in total eight channels of calibration output.

The various channels of data are transmitted via the telemetry link to the ground station in bursts of data. In order to avoid unnecessary signal drift, the eight calibration outputs are transmitted in bursts in pairs, one member of each pair relating to a receiving means on the lower part of the target aircraft, the other member relating to the most closely coupled receiving means on the upper part of the target aircraft, and so on. Each burst of calibration output contains a waveform of duration slightly greater than 1/f, so that the waveform contains two direct transmit signals. This makes processing easier.

## 2. DATA COMPRESSION

The preferred embodiment of missile scoring radar system produces a large amount of data which has to be transmitted by radio telemetry from the target aircraft to the receiving ground station. There are, simultaneously, data from 48 range gate channels (8 receivers each having 6 range gates). The data rate is high, in order to cope with fast-moving missiles. The amount of data to be transmitted hence requires a large telemetry bandwidth.

In the preferred embodiment of the second aspect of the invention, concerned with data compression, a scheme is presented for compressing the data during transmission from the target aircraft in order to reduce the telemetry bandwidth. The data is then decompressed at the ground station. Whilst this second aspect is described herein in the context of a scoring radar system, it is not limited to such a system.

In overview, the data compression procedure is as follows.

1) The analogue signal at each instant is digitised at high dynamic range (8 bit or greater in the preferred embodiment). The sequence of data samples thus digitised

is referred to as $x_i$.

2) The digitised data samples are buffered up into blocks of multiple samples.

3) For each channel and each block, the maximum absolute difference between two successive samples is evaluated (that is, max $|x_i-x_{i-1}|$ is evaluated) for all but the first sample of the block (see Step 8 below).

4) One exponent exp per block (a block data value) is defined which when 2 is raised to the power of the exponent and then multiplied by (2,1,0,-1 or -2) will exceed the maximum difference (max $|x_i - x_{i-1}|$) evaluated in Step 3 above.

5) Each data sample is encoded to form an individual data value by finding the best value of r from the set (2,1,0,-1 and -2) which when multiplied by $2^{exp}$ minimises the difference between the current sample and the last reconstructed value (see Step 6 below). The sequence of encoded individual data values is known as $r_i$.

6) The new "last reconstructed value" is evaluated as the previous last reconstructed value plus r times $2^{exp}$, and is known as $y_i$.

7) Each set of 3 consecutive values of r is combined into a respective 7 bit word equal to the sum of $(r_{i-2}+2) + 5*(r_{i-1}+2) + 25*(r_i+2)$.

8) For each new block the first difference used in defining the exponent is $x_i$ (that is, from the new block) minus $y_{i-1}$ (that is, from the previous block). This ensures that any residual error from the previous block does not accumulate from block to block.

The scheme outlined above is herein referred to as the "differential block floating point scheme". Significant features of the differential block floating point scheme are now described in greater detail.

Firstly, the scheme is herein termed a differential scheme, by which is meant that each compressed, encoded data value is evaluated in dependence upon the difference between two data samples to be compressed, rather than representing the absolute value of a data sample to be compressed. This allows compensation to be made automatically for any d.c. offsets in the data (such as frequently occur in data from radar systems).

Secondly, the scheme operates in blocks, with a data value characteristic of a whole block being evaluated, as well as individual data values characteristic of the individual data samples. This affords a scheme which reacts quickly to sharp variations in the magnitude of the underlying data stream, and hence follows the data stream without significant time lag or lead.

In the preferred embodiment, there are either 6 or 9 data samples per block. At a data rate of 31kHz a block length of 6 samples has been found to operate satisfactorily in practice without undue distortion. In different circumstances, other block lengths might be appropriate, although in the preferred embodiment they would need to be a multiple of three samples. With short block lengths, the data samples can be followed more accurately, but the data rate is higher.

Thirdly, the scheme is termed a "floating point" scheme, by which is meant that the data is represented in mantissa and exponent form.

The exponent (exp) is a data value characteristic of the

entire block. It is intended to be representative of the dynamic range of the data in the appropriate block. In the preferred embodiment, the exponent is 3 bits long, so that $2^{exp}$ can vary from 1 to $2^7$ (128).

In the preferred embodiment, the exponent is the nearest integral value of $\log_2$ (4/3* maximum absolute difference), since this has been found to be optimal. However, for different applications, logarithms to different bases might be appropriate. Alternatively, the exponent might be chosen from a look-up table.

The decoding process, which would typically be carried out at the ground station, is the inverse of the above encoding process.

Another realisation of the data compression scheme is exactly as above except that the exponents are defined from the biggest absolute value of the digitised samples $x_i$ rather than the differences $x_i-x_{i-1}$. This scheme herein is referred to as the "absolute block floating point scheme".

Returning again to the differential block floating point scheme, the mantissa (r) is a (compressed) data value, one for each individual sample. The mantissa is in fact highly compressed, taking one of a set of only five possible values, -2, -1, 0, +1, or +2. The existence in the set of the value "zero" is significant, since the scheme can thereby cope easily with long periods when the data stream does not vary significantly in value.

Fourthly, the data compression scheme stores the individual data values representative of the individual data samples in sets of 3, two sets to a block, as a single 7 bit word. A 7 bit word can take one of 127 possible different values. Since each data value has a possible 5 values, a set of 3 data values has $5^3$ (equals 125) possible different values.

Hence the division of the block into sets in this way can permit economical data transfer.

Fifthly, an important feature of the data compression scheme is its ability to cope with fading of the transmitted signal. If the signal fades, clearly it may be impossible for the ground station to receive any reliable data during the period of fading. This presents a particular problem when the differential scheme is used, since in this event recovery of the true absolute level of the data stream is impossible without further information. To combat this, every, say, 24 blocks the absolute value of a data sample is transmitted, along with a synchronisation word to allow the data stream to be re-synchronised. Given the absolute value, this can then be propagated back in time to retrieve data samples back to the point at which the transmission fade ceased.

Sixthly, further data compression may be achieved by using the same exponent for the output from some or all of the receiving means.

The preferred embodiment of data compression apparatus according to the present invention is explained with reference to Figure 4. In the example given there are 48 channels and the exponent is defined with respect to blocks of nine samples, but the radar system could of course have any number of channels and the exponent could be defined with respect to an arbitrary number of samples.

The preferred embodiment of data compression apparatus comprises a first Random Access Memory (RAM) 201, a second RAM 202, a third RAM 203, a first subtractor 204, a first Programmable Read Only Memory (PROM) 205, a second subtractor 206, a second PROM 207, and an adder 208. The input to the apparatus is a new data input sample which is provided to the line marked "Input"; the output is an

encoded (compressed) data value including both a mantissa and an exponent (see the line marked "Output (Mantissa and Exponent)").

In overview, the apparatus operates in the following fashion. The new input sample is subtracted from the last previous input sample, which has been stored in the RAM 201, by the subtractor 204. The exponent corresponding to the result of this subtraction is compared by the PROM 205 with the current exponent and is updated if the new difference is larger. The new exponent is written back into the RAM 202. The corresponding sample in the previous block is subtracted by the subtractor 206 from the last reconstructed value held in the RAM 203. The resultant difference is then encoded by the PROM 207 which outputs the mantissa and exponent as the output of the apparatus. The value of r x $2^{exp}$ is also output from the PROM 207 to the adder 208. This adder adds this value to the last reconstructed value and hence updates the last reconstructed value in the RAM 203.

The following is a detailed description of the various operations which are required to compress 9 data samples into a single data block. The description proceeds with reference to three time-consecutive data blocks, n-1, n and n+1. The entire sequence of operations is repeated for each of the 48 data channels.

For each of the samples 2 to 9 in block n(n,2 to n,9):

Increment the sample number from 2 to 9 and the channel number from 1 to 48 for each of Stages 1 to 3. That is:-

For sample = 2 to 9
For channel = 1 to 48

**STAGE 1**

For block n

Read the previous value for this channel from Random Access Memory 201 (n, sample-1) and latch.

Read the current exponent from RAM 202 ("new" exponent) and latch.

For block (n-1)

Read the exponent for the previous block from RAM 202 ("old" exponent) and latch.

Read the "last reconstructed value" for the previous block from RAM 203 (n-1, sample-1) and latch.

**STAGE 2**

For block (n-1)

Read the next sample from the previous block from RAM 201 (n-1, sample) and latch.

Calculate the difference between the last reconstructed value (n-1, sample-1) and the next sample (n-1,sample) in subtractor 206.

Code this difference in PROM 207, and pass the coded word (r) to a framing circuit (not shown), which arranges the coded words in the desired order for transmission.

Add the transmitted difference ($r \times 2^{exp}$) using the adder 208 to the last reconstructed value (n-1, sample-1) to give the new "last reconstructed value" (n-1, sample).

STAGE 3

For block n

Write a new sample (n, sample) into Random Access Memory 201.

Subtract the previous value (n, sample-1) using subtractor 204 and update the "new" exponent using the PROM 205.

Write the "new" exponent to the RAM 202.

For block (n-1)

Write back the "old" exponent (unchanged) to the RAM 202.

Write the new "last reconstructed value" (n-1, sample) to the RAM 203.

Next channel

Next sample

Thus, at this time, one of the RAM's (the RAM 201) contains the 48 channels of the nth block of 9 samples. We have also stored the last reconstructed value of block n-1 and the exponents for block n-1 and block n based on all differences except the difference between the first sample of the nth block and the last reconstructed value of block n-1. The sequence of operation then proceeds as follows.

For the first sample in the next block (n+1,1):

Increment the channel numbers from 1 to 48 for each of the following stages. That is:-

For channel = 1 to 48

STAGE 4

For block n

Read the "new" exponent from the RAM 202 (for block n) and latch.

Pass the "new" exponent to the coding PROM 207 to form part of the coding equation.

Read the last reconstructed value (n-1,9) from the RAM 203 and latch.

STAGE 5

For block n

Read the first sample of block n (n,1) from the RAM 201 and latch.

Subtract the last reconstructed value (n-1,9) from sample (n,1) using the subtractor 206. Increase the size of the "new" exponent (exp) if necessary.

Code the difference (r) using the PROM 207, and pass the coded word (r) to the framing circuit.

Add $r \times 2^{exp}$ using the adder 208 to the last reconstructed value (n-1, 9) to give the new "last reconstructed value" (n,1).

STAGE 6

For block (n+1)

Write the new sample (n+1,1) into the RAM 201.

<u>For block n</u>

Write the "new" exponent updated in Stage 5 into the "old" exponent memory (RAM 202). Write zero into the "new" exponent memory.

Write the new "last reconstructed value" (n,1) also calculated in Stage 5 to the RAM 203.

Next channel.

It will be appreciated that the data compression apparatus described above could be implemented in several alternative forms. It might, for example, be implemented on a programmable processor, in discrete digital logic, in an Application Specific Integrated Circuit, or in field programmable gate arrays.

## 3. <u>REAL TIME SIGNAL PROCESSING FOR THE SCORING RADAR SYSTEM</u>

### 3.1 Overview

The operation of the scoring radar system known from International Patent Application No. PCT/GB90/00602 has already been described. In the preferred embodiment of the present invention, two main enhancements have been made to this system to increase the reliability of the scoring process, and also to enable signal processing to occur in real time.

The first enhancement is that the energy bandwidth used for basic detection is rendered velocity dependent. In other words, a missile proximity score is derived at each channel by measuring the energy in a Doppler frequency bandwidth corresponding to the missile velocity. This velocity, which

is unknown at the time of the test, is estimated by measuring the Doppler shift.

The second enhancement is that, because the range gates of the scoring radar system are of known spacing, given the missile velocity, a prediction can be made as to when a missile of a velocity measured at one range gate would be expected to arrive at the next range gate.

Hence, for a given receiver, the likely presence of a missile can be identified based on a positive detection at the same velocity (or related pattern of velocities if acceleration is significant) over a number of range gates.

Finally, an engagement is scored if multiple receivers identify the likely presence of a missile at the same (or similar) velocity.

The multi-stage approach described above can afford significant protection against false alarms caused by received interference or clutter, because these phenomena are unlikely to be correlated in frequency (and hence apparent velocity) at different channels. Furthermore, to the extent that noise occurs at different channels at the same frequency, it is unlikely that it will occur in the correct sequence to pass the test of being consistent at a given receiver. In the unlikely event that this occurs then it is unlikely that the interference will present this consistently to the other receivers.

3.2 Background to the Preferred Embodiment of Scoring Radar System

In the preferred embodiment of scoring radar system, eight receivers and six range gates are provided, which can detect missiles with speeds from 200 to 8000 feet per second (roughly 60 to 2500 metres per second). The range

gates are set at 40, 60, 80, 100, 110 and 125 feet (roughly 12, 20, 25, 30, 35 and 40 metres). Each range gate is a mere roughly 1 inch (2.5cm) in thickness. Each gate is sampled at a data rate of approximately 35 kHz and the samples are converted to 10-bit digits. In alternative embodiments, the range gate spacing might be as great, say, as 100 or even 500 feet (30 or 150 metres) or as little as, say, 5 or even 1 foot (1.5 or 0.3 metres).

For data compression purposes (for which see Section 2 above), the data is encoded using a differential block floating point scheme. Each sample has a five level mantissa and 3 successive samples are packed into 7 bits and send a new exponent for every group of 9 (or possibly 6) samples.

Given the range of target speeds to be detected and the setting of the range gates, the fastest time between range gate crossings is 2.5 ms, while the slowest is roughly 100ms. The maximum total encounter time is 1.25 seconds.

### 3.3 The Scoring Algorithm

#### 3.3.1 Overview

The scoring algorithm described in this section is required to perform well in the presence of various types of noise. This includes white noise, impulsive noise and narrow band interference. To perform well, the algorithm should not fail to detect a genuine engagement, but should have a low false alarm rate.

The algorithm described herein is applicable to detection of a moving object (such as a missile). In the case of missiles, the relative trajectory of the missile relative to the target aircraft is approximately linear and hence the range-time curve with respect to an individual receiver

(assuming both approach and recession of the missile) is approximately hyperbolic. The present algorithm functions to match the detection process to the known geometric (approximately hyperbolic) evolution pattern of the missile with respect to the receivers. This involves looking for a sequential pattern of range gate crossings representing the approach of the missile. The algorithm also allows the possibility of looking for a similar pattern as the missile recedes. This feature can be used to ascertain physically possible detection sequences.

In addition, as described previously, the algorithm takes advantage of the fact that the signals of interest from a missile travelling at a particular speed are confined to a limited bandwidth. (This follows from a consideration of the Doppler effect.)

One of the difficulties to be overcome is the wide range of possible missile speeds. This is dealt with by searching in the frequency domain for cumulative activity corresponding to a set of assumed missile speeds which cover the full range from 200 to 8000 ft/s (roughly 60 to 2500 m/s). For each speed in the set, a separate attempt is made to determine whether there is a corresponding set of range gate crossings.

The search for sequential patterns of range gate crossings (so-called "pattern matching") is carried out independently for each receiver. This yields a set of scores, one per receiver, one per assumed speed, which are related to the number of range gates that have been crossed at that speed.

The task of amalgamating the scores produced by each receiver into an overall assessment of the engagement and hence an overall engagement score involves looking for consistent evidence at the same speed of a likely engagement from two or more receivers.

In outline, the steps performed in the algorithm are:-

1) Decompress the data, by inverting the five level differential block floating point coding described in Section 2 above.

2) Buffer up data in buffer blocks of 512 samples per channel. Thus a storage capacity of 24k words is required at this point.

3) Implement Fast Fourier Transforms on the data (without overlapping). The FFT processing is invoked twice on each block of 512 samples, once to do 2 x 256 point FFT's and once to do 8 x 64 point FFT's. (Alternatively, equivalent processing could be accomplished using wavelet transforms, where the frequency bins are formed by recursive filters implemented in the time domain.)

4) Square the output from the FFT processing to obtain power spectral estimates.

5) Sum the spectral estimates to estimate the power in various velocity bins, that is, those corresponding to a series of different missile velocities. Downsample these estimates by various amounts (that is, sample them at different rates) according to velocity.

6) Form a background noise estimate. The estimate is delayed before being used so that recede events can be detected.

7) Threshold current energy in the velocity bin bandwidth against a multiple of the (background) noise plus a quantisation limit (or an absolute value if appropriate).

8) Thus obtain a detection decision for each range gate, for each velocity bin and each receiver, at a rate which is scaled approximately according to velocity (see Step 5 above).

9) For each receiver, look for patterns of detections across all range gates that match those expected for approach or recede events, to derive an overall detection decision, and hence an overall score, for that receiver.

10) Derive an overall engagement score based on the overall detection decisions for each receiver.

The main features of these steps are described in the succeeding sub-section. Apparatus to put the algorithm into effect is described in Section 4 below.

3.3.2 The main processing steps of the scoring algorithm

For convenience, the scoring algorithm is described as a number of processing steps, although there is nothing fundamental about the manner in which the steps have been divided.

Step A: Divide signals into frequency bands

Signal to noise ratio improvement and velocity selectivity is gained by dividing the signal into a number of frequency bands ("bins") (in the present embodiment sixteen). Subsequent processing steps will search for a missile of a particular speed only in the frequency band in which its signature is expected to fall.

The incoming signals are transformed twice by Fast Fourier Transform, once in blocks of 64 and once in blocks of 256. This is done to achieve a good compromise between time

resolution and frequency resolution. In the lowest velocity band, a longer FFT is needed in order to obtain sufficient frequency resolution. 256 samples gives 137 Hz resolution, which corresponds to a speed resolution of around 40 m/s (compared with the slowest possible missile speed of roughly 60 m/s). In the higher velocity band, a shorter FFT is needed in order to achieve adequate time resolution. 64 samples occupies a time of 1.8 ms (at 35 kHz sampling frequency), which is comparable with the duration of the missile signature at the fastest speed.

As mentioned above, an equivalent process could use wavelet transforms, to obtain power estimates in the various frequency bands.

The data is transformed to the frequency domain and power spectral estimates computed by squaring and adding the real and imaginary outputs from the FFT.

The data is processed in 16 velocity bins and thus the velocity resolution of the system is ±12.5 %. Other numbers of velocity bins may be appropriate, maybe as low as 4 or as high as 32 or 64. For the efficiency of the FFT processor, a number of bins which is a power of two is preferable. The power in each velocity bin is computed from the sums of the FFT spectral estimates. These velocity bin estimates are then downsampled by summing together the powers from consecutive time samples. The downsampling rate is chosen according to velocity bin such that the time between samples is comparable with the duration of the missile signature at that velocity. This ensures that the signal to noise ratio is optimised, and also permits the pattern of movement of the missile to be matched against a single pattern, regardless of velocity. Also, for a given velocity bin, the downsampling rate is preferably chosen such that the number of detection samples per range gate crossing is in the range 1 - 2.

The table below shows how the full range of velocities can be divided into 16 velocity bins. The table provides, for each velocity bin, the median velocity, the bounds of the Doppler frequency bands covered by the relevant bin, the engagement time, the size of the Fast Fourier Transform, the number of FFT bins employed, the downsample rate, and the overall downsample rate (computed as the downsample rate times the FFT size).

| Median Velocity (m/s) | Doppler (Hz) | Engagement Time (sec) | FFT size | FFT bins | Down-sample rate | Overall downsample rate |
|---|---|---|---|---|---|---|
| 88 | 136, 528 | 1.25 | 256 | 2, 5 | 6 | 1536 |
| 110 | 220, 660 | 0.692 | 256 | 3, 6 | 5 | 1280 |
| 138 | 276, 828 | 0.552 | 256 | 4, 8 | 4 | 1024 |
| 172 | 344, 1032 | 0.443 | 256 | 4, 9 | 3 | 768 |
| 215 | 430, 1290 | 0.354 | 256 | 5, 11 | 2 | 512 |
| 269 | 538, 1604 | 0.283 | 256 | 5, 13 | 2 | 512 |
| 336 | 672, 2016 | 0.226 | 256 | 6, 16 | 2 | 512 |
| 420 | 840, 2520 | 0.181 | 256 | 8, 20 | 1 | 256 |
| 524 | 1048, 3144 | 0.145 | 64 | 3, 7 | 4 | 256 |
| 656 | 1312, 3936 | 0.116 | 64 | 3, 8 | 3 | 192 |
| 820 | 1640, 4920 | 0.093 | 64 | 4, 10 | 3 | 192 |
| 1024 | 2048, 6144 | 0.074 | 64 | 5, 12 | 2 | 128 |
| 1281 | 2562, 7686 | 0.059 | 64 | 6, 15 | 2 | 128 |
| 1601 | 3202, 9606 | 0.048 | 64 | 7, 19 | 1 | 64 |
| 2001 | 4002, 12006 | 0.0381 | 64 | 8, 23 | 1 | 64 |
| 2501 | 5000, 14628 | 0.031 | 64 | 10, 28 | 1 | 64 |

The Doppler frequency bands overlap quite significantly. The extent of their overlap can be seen from Figure 5, where the bands are plotted according to their respective velocity bins. The Doppler frequency bands are chosen to admit the majority of energy in a signal (>87%). The downsampling rates are chosen such that the time window over which each downsampled power estimate is formed is just greater than the duration of the typical missile signature. This ensures that, for each range gate crossing, there is a single downsampled power estimate which contains more than half the energy of the missile signature. Figure 6 illustrates this. In this figure are shown the best and worst cases, that is respectively where the signature lies entirely within one time window and

where the signature spans the junction between one window and the next equally.

The pattern of Doppler observed over an engagement depends on the closest distance of approach of the missile to the receiver (the "miss distance"). This point is illustrated in Figure 7. This figure shows how the radial component of velocity varies for different scalar miss distances. The six different symbols represent the six range gates, the uppermost symbols on the figure representing the outermost range gates. In the worst case (the fourth gate out, represented by the full diamond symbols), the radial velocity can vary by a factor of 2.5 over the engagement. Such a change in velocity corresponds to a wandering of the signal through up to 5 velocity bins from outer gate to inner gate. This leads to a 4 dB signal attenuation in the bin detecting the missile at the outer gate compared to the inner gate. In the worst cases, the missile flies further between detections than when it has a low miss-distance and so the difference in time intervals between events is little changed.

Step B: Noise estimation and thresholding

At this stage in the procedure there is a set of 16 signals (that is, one per velocity bin) associated with each of 48 channels (8 receivers with each having 6 range gates). As mentioned above under Step A, the sampling rate for each velocity bin is different.

In Step B, an estimate is made of the background noise, a threshold value of noise is derived, and the signal peaks are compared with this threshold value. In the preferred embodiment, the signal peaks are compared with a threshold value which is delayed by at least two engagement times so that the detection of recede events is not inhibited by the

higher thresholds which will be caused by the target activity. The relevant engagement time is the slowest possible engagement time, in other words, 1.25 seconds.

The easiest method of achieving a noise estimate is by what is termed herein the "block method". Essentially this involves forming a noise estimate by averaging the signal values over a block of samples. Each block is typically around 8 seconds in duration, in other words, considerably longer than twice the slowest engagement time, so that neither the missile approach nor recede can desensitise the receiving means. On the other hand, the block length is preferably not too much longer than twice the slowest engagement time, since the expected noise is not "stationary" (in other words, it can vary quite rapidly with time). The block length is also preferably chosen so that in multiple missile firings a first missile does not so desensitise the receiving means that it prevents a second missile fired shortly after the first from being detected.

When a block of signal values has been formed, the result is converted into a threshold by multiplying by a constant (say 4) and adding another small empirically derived constant (to avoid excessive sensitivity when the noise level is low). The resultant threshold value is then fed into a delay line of a few seconds in duration, and stored for use at a later time. The choice of the duration of the delay line is made on similar principles to the length of the block (see above). In order to avoid sudden steps in the threshold it is possible to calculate an incremental value which takes the threshold from the current level to the level to be used at the end of the next block.

The above process can be implemented very efficiently computationally. This is because most of the work is done at the end of a block, say every 16 or 32 samples.

Normally, when each sample arrives, only two additions are required, one to sum the noise power in the current block, and one to add the increment to the threshold. Provided the block lengths are chosen to be powers of two, any divisions necessary are simple shifts.

Because there are separate velocity bins, in principle the noise estimation could be optimised according to the velocity. In practice, because the data samples have already been downsampled in accordance with velocity, the optimum for each velocity is to carry out the identical process.

Having defined a threshold noise value, each new power sample is compared with the threshold to decide whether there has been a detection or not at the particular range gate and receiver. This decision is represented as a single bit of information (1 or 0). The single bit is shifted into the bottom of a 16 (or possibly 32) bit word to maintain a record of the most recent pattern of detections.

Due to the structural complexity of the above operations, the downsampling, noise estimation and thresholding are implemented in the preferred embodiment with a programmable processor.

Step C: Processing detections from a particular receiver (pattern matching)

As mentioned in Section 3.3.1 above, a physically realistic range gate crossing sequence is hyperbolic. Such a sequence is shown in Figure 8. This figure provides a plot of the bistatic range of the missile against time. (The "bistatic range" is the sum of the ranges of the missile as measured between a physically separate radar transmitter and receiver and the missile.) The plot is for a missile

travelling at a constant 180 m/s velocity and for a nearest miss distance of 7 metres.

In the preferred embodiment, as mentioned above, for each of the 16 velocity bins, for each of the 6 range gates, for each of the 8 receivers, there is a 16 bit word defining the recent detection history. The next task therefore is to look at the recent detection history for all the range gates associated with a particular receiver (that is, at the evolution pattern of the detection signals) and determine whether the pattern of detections is indicative of likely engagement, thereby to determine an overall detection decision for the particular receiver. For example, in Figure 9 are illustrated two acceptable patterns attributable to an engagement that crosses all gates (if the gates are equally spaced). The first example represents a higher velocity engagement, the second represents a lower velocity engagement, both engagements being shown for the same velocity bin and therefore at the same downsampling rate. Only the approach pattern is shown. If a recede pattern were also included, then the pattern taken as an entirety would appear roughly hyperbolic.

In order to convert the above principles into a suitable pattern matching algorithm, a set of rules has to be defined as to what are acceptable patterns and what are not. The basic rules are described below:

1) The detection of interest at a particular range gate is the first one after a period of no detections. Subsequent detections are irrelevant, because in a typical engagement plenty of subsequent detections are to be expected, for example, due to multi-path reflections.

2) The detections of interest are preferably stepped by an amount ranging between one and two time steps per

range gate, to avoid either too much or too little data being generated for each range gate.

3) Due to the imperfections of real life, limited irregularities are tolerated, such as a detection at one range gate in advance of a correct detection pattern, or the absence of a detection at one range gate. However, the detections must in general progress monotonically.

4) Detections at outer range gates only are regarded as indicative of greater miss distance.

Note that an equivalent, time reversed, set of patterns can be defined for recede events. However, if the target aircraft is actually hit, then the pattern of recede detections is arbitrary because target fragments may be detected.

The implementation of the above pattern matching can be achieved using a small amount of custom logic and a Programmable Read Only Memory. Alternatively, it may be carried out in a programmable processor. The actual implementation employed in the preferred embodiment is described in more detail in Section 4.6 below.

In the remainder of this sub-section, the logic necessary to define a gate score for each range gate (at each velocity bin value), and to convert the gate scores for each receiver at each velocity bin value into an overall detection decision and score for the individual receiver, for one particular velocity bin, is described. In order to do this, reference is first made to Figure 10, so that so-called "first and second points of engagement" can be defined. These points of engagement actually appear as lines on the detection signal pattern shown in Figure 10, emanating from a common point at the outermost range gate, and defining therefrom the slowest and fastest acceptable detection patterns, corresponding, respectively, on the one

hand, to the slowest possible missile speed and maximum miss distance and, on the other hand, to the fastest possible missile speed and minimum miss distance. Patterns falling between these extremes are deemed to be acceptable.

The logic necessary to define a gate score for each range gate is as follows:

a) If there are any detections in the period before the first point of interest (that is, in the tail of the pattern, as illustrated in Figure 10), a gate score of -1 is assigned. The length of the tail needs to be chosen; this is typically 15 samples in the preferred embodiment. A negative score is given since detections in this region would not be consistent with the approach of a missile.

b) If there are no detections up to and including the second point of engagement, the gate score is 0.

c) If there are detections between the first and second points of engagement, a score is assigned which indicates the position of the first detection from the first point of engagement.

The various possible gate scores, and the number of bits required to represent them, is as follows:

| | | |
|---|---|---|
| Outer gate: | -1, 0, 1 | 2 bits |
| Gate 5: | -1, 0, 1, 2 | 2 bits |
| Gate 4: | -1, 0, 1, 2, 3 | 3 bits |
| Gate 3: | -1, 0, 1, 2, 3, 4 | 3 bits |
| Gate 2: | -1, 0, 1, 2, 3, 4, 5 | 3 bits |
| Inner gate: | -1, 0, 1, 2, 3, 4, 5, 6 | 3 bits |
| | | ------- |
| | TOTAL: | 16 bits |

Referring to Figure 10, the various gate scores basically

represent the number of down-sampled periods from the detection at the outer gate to a detection at a closer gate. A score of -1 means a detection in advance of the line representing the first point of engagement. A score of 0 represents no detection. A score of 1 represents a score actually on the line representing the first point of engagement. A score of 2 represents a delay of one unit from the line representing the first point of engagement, a score of 3 represents a delay of two units, and so on.

The 16 bits can then be input into a PROM in the form of a look-up table or the like to determine whether the pattern is acceptable or not, with the various gate scores acting as address information for the look-up table. The output of the PROM will be an overall detection decision score for the individual receiver, for one particular velocity bin. (This is also termed "the instantaneous score for the receiver, velocity combination".) Since the PROM which is used has an 8 bit output, this output is used to contain both information about the quality of the engagement and also other miss distance information, most specifically how many range gates the missile has crossed.

Ultimately, an overall assessment of the engagement is provided on the basis of the instantaneous velocity combination scores for all the receivers. To allow for the skew between different receivers a time history of the scores for each receiver is stored, corresponding to the maximum time offset between receivers. In the present embodiment, in one down-sampled time period the missile would travel at least 3 m, and so this history need only be three samples per velocity bin per receiver.

Step D: Amalgamate results from all receivers

The instantaneous velocity combination scores from each of the receivers for each of the velocity bins are amalgamated

to provide an overall assessment for the likely engagement.

Although there are several possible ways of providing an overall assessment, in the preferred embodiment an engagement is scored at a particular velocity bin if the score, for each velocity bin, totalled across all the receivers is greater than six, and, to be more precise, if more than two receivers score more than 3 range gates or more than 3 receivers score two consecutive range gates in any of the sixteen velocity bins (the score being calculated as the number of range gates times the number of receivers). The latter condition (more than 3 receivers scoring two consecutive range gates) arises in order to detect a missile which only traverses the outermost range gates (say, those range gates beyond 100 feet, 30 metres). Approach and recede detections may be combined in this score but an engagement is not scored if one receiver scores on approach and recede only. Due allowance must be made for the skew between the hyperbolic range - time curves of the different receivers (the centre of the ellipsoids may be separated by 6 metres and so the skew of the curves might be this distance divided by the speed).

Thus the overall engagement score for a given velocity bin is evaluated from the maximum scores from the individual receivers at the last three time periods in down-sampled time. Where an engagement is scored at multiple velocity bins the engagement at the lowest velocity bin is the one which is taken into account, since this is likely to contain the most complete information concerning the engagement. In practice, the lowest such velocity bin is usually likely to have a velocity range centred somewhat lower than the true missile velocity owing to the reduction in the missile tangential velocity as it passes the target aircraft.

The typical result obtained from a real engagement in time

domain simulations is that potential engagements are registered at more than one of the assumed speeds, for example at the actual speed and at each of the adjacent speeds. These tend to be fairly consistent in the estimated time of arrival. Occasionally, apparently spurious engagements are registered in other velocity bins on signals that occur during the engagement, that is, those due to multipath, acoustic noise, and so on. This set of potential engagements can be sorted quite easily by looking at the overall engagement scores (figures of merit) for each one. In general, the result that yields the highest overall engagement score is that which most accurately indicates the missile's speed and time of arrival. Indeed, the existence of the other results can be used as supporting evidence that a true engagement has actually been detected.

The estimate of missile speed yielded by the potential engagement with the highest overall engagement score can then be confirmed or refined by comparing the approach and recede results. Since the approach result yields a time of arrival at the outer gate, and the recede result yields a time of exit, another approximate estimate of missile speed can be made. If this is consistent with the first estimate of missile speed one can have further confidence that the algorithm has correctly identified the actual range gate crossings in both approach and recede.

An alternative preferred embodiment takes into account more fully the fact that the Doppler varies from outer gate to inner gate. In this embodiment, final processing is carried out across some velocity bins. For example, detection signals from lower velocity bins at closer range gates may be combined with detection signals from higher bins at farther gates.

## 4. ARCHITECTURE AND PROCESSING LOAD CALCULATIONS

### 4.1 Architecture

The architecture of one preferred embodiment of the ground station portion of the missile scoring radar system of the present invention is now described with reference to Figure 11. This figure also shows the rate at which data is transferred between the various hardware elements.

The incoming data stream received via a receiving antenna (not shown) on the ground station is first passed to Programmable Read Only Memory or programmable processor 400 where the data which had been compressed on the target aircraft, and then transmitted down the telemetry link, is decompressed.

The decompressed data stream is passed at a data rate of 1.68 M words per second to a 24k by 10 Buffer RAM 402, and thence, at a rate of 3.35 M words per second, to an FFT processor 404, described in more detail below.

The output of the FFT processor 404 is taken at a rate of 1.68 M words per second to first and second multipliers 406 and 408, whose outputs are themselves added by adder 410. The FFT processor 404, multipliers 406 and 408 and adder 410 function to produce an output which represents power spectral densities at various frequencies. Their function is described in more detail in Sections 4.2 and 4.3 below.

In an alternative preferred embodiment, instead of an FFT processor, a processor carrying out a similar function (such as a wavelet transform processor) could be used.

The output from the FFT processor 404 is in floating point format. Thus, in shifter 412 this output is scaled appropriately, and then buffered in a 64k by 32 Buffer RAM

414. The RAM 414 holds frequency bin data. Data is output from the Buffer RAM 414 at a rate of 2.4 M words per second to an accumulator 416, which sums the data received over a period of time then outputs it at a rate of 264 k words per second to an 8k by 32 Dual Port RAM 418, which holds velocity bin data. The operation of these devices above is described in more detail in Sections 4.3 and 4.4 below.

The RAM's 402, 414 and 418, the FFT processor 404 and the accumulator 416 are all controlled, and in some cases also addressed, by the state machine controller 420. This controller is fed with the clock output from the PROM 400.

The output from the Dual Port RAM 418 is passed at a rate of 264 k words per second to a 68030 programmable processor 422 from Motorola Inc., although it will be understood that any similar 32-bit digital processor would suffice. As described in more detail in Section 4.5 below, the processor 422 functions to downsample the data, produce a noise estimation, and to compare the data with a noise threshold.

The output from the processor 422 is passed at a rate of 152 k words per second to a PROM 424 and associated logic circuitry which function as a pattern matcher in a manner described below in Section 4.6.

The output from the PROM 424 is passed at a rate of 25.3 k words per second to a 680x0 programmable processor 426 from Motorola Inc., although again it will be understood that any similar processor would suffice. The processor is for receiver amalgamation, as described in more detail below in Section 4.7.

In a final step in this portion of the procedure, the output from the processor 426, in the form of information on missile engagements, is passed at a low rate to a 68 k

processor 428.

The PROM 400 passes calibration data and the like to the processor 428. It also passes, in another portion of the procedure, all the decompressed data to a 4 Mbyte Buffer RAM 432, which accumulates current data on the fly, constantly overwriting less recent data. The purpose of the Buffer RAM 432 is to keep a rolling memory of data so that, if the processor 428 recognises a potential engagement, the relevant portion of the data can be passed, under the control of the processor via an interface 430, to a Direct Memory Interface 434, thence to a Small Computer Standard Interface (SCSI) 436, and finally to a workstation (not shown), where the data can be assessed in detail.

The preferred embodiment described above would be relatively inexpensive to implement, but relatively inflexible. In another preferred embodiment, which would be more expensive but more flexible, all the functions described with reference to Figure 11 are implemented on an array of, say, eight digital programmable signal processors, such as the Texas Instruments TMS 320C40, together with appropriate data storage facilities. In this event, not even the state machine controller would be required.

In this case a processing engine is formed within a VME (trade mark) architecture comprising 8 TMS320C40 processors on Motherboards such as the Loughborough Sound Images (LSI) DBV42 and DBV44. These Motherboards offer 2 TMS320C40's on the DBV42 and up to 8 such processors on the DBV44. The DBV42 also has up to 16 M words of RAM for the revolving buffer. The processors would be allocated to functions as follows:-

1. Processor 1 - Data input and decompression
2. Processors 2 to 5 - FFT or Wavelet Transform

3. Processor 6 - Velocity bin formation
4. Processor 7 - Downsampling, noise estimation, thresholding and pattern matching
5. Processor 8 - Receiver analgamation

Various features of the preferred embodiment of the ground station portion of the missile scoring radar system of the present invention are mow described in greater detail, still with reference to Figure 11.

## 4.2 FFT Processing

The FFT processing is planned around a custom FFT chip, in the preferred embodiment the Plessey PDSP16510 stand alone FFT processor, as the processor 404. As discussed above, it could alternatively be implemented on an array of Digital Signal Processing chips such as TMS320C40 (Texas Instruments), or on a standard programmable processor. If the TMS320C40 chip were used, four processors would be required to implement the FFT; in this case the hardware would be commercial-off-the-shelf, but relatively expensive.

Each group of 512 time-consecutive range gate data samples is processed twice, once with the FFT processor in the 2 x 256 point mode and once with the processor in the 8 x 64 point mode. The most efficient method of doing this is to process all channels in one mode, then process them all again in the other mode. This is because the FFT processor normally accepts input data, transforms a set of data, and outputs data in a parallel (pipeline) fashion. Before changing mode, it would be necessary to complete the retrieval of output data before commencing the input of new data.

The fact that each batch of channel data needs to be processed twice means that it must be fed into the FFT processor twice. This is not a problem because it is necessary anyway to buffer the data before the FFT input (in the Buffer RAM 402) in order to unscramble the channels that arrive from the telemetry link.

The required processing load is 48 lots of 2 x 256 point transforms and 48 lots of 8 x 64 point transforms, plus time to change mode twice, in 14.6 ms (where 14.6 ms corresponds to 512 samples at 35000 Hz). A 2 x 256 point transform takes 25.8 $\mu$s in the Plessey chip, while the 8 x 64 point transform takes 20.5 $\mu$s (assuming a clock rate of 40 MHz). The processing time required is therefore 2.2 ms. Allowing another four periods to get data in and out at the changeover, this increases to 2.3 ms. Thus the chip would only be 16% utilised.

### 4.3 Squaring of FFT Outputs

The next stage is to square and then sum the FFT outputs in order to convert the real and imaginary values of the output into power spectral densities. For this, the real and imaginary FFT outputs are passed to the respective multipliers 406 and 408 and thence to the adder 410 for squaring and adding on the fly. The outputs of this process are then dumped in the Buffer RAM 414 via the shifter 412 for subsequent resorting. The multipliers and adder are custom chips.

For each FFT there is one complex output for every two real inputs. Given that all input data is processed twice, there is one complex output to be processed per input sample. Thus, complex outputs must be processed at a rate of 48 x 35000 Hz = 1.68 MHz. Assuming that two multiplier chips are used, they must be able to process faster than 590 ns each. In practice, the output data will be

extracted in a more bursty fashion and faster multiply rates will be required. However, since appropriate multipliers are readily available to less than 100 ns, for example a Cypress (trade mark) CY7C516 chip, there is no problem.

### 4.4 Formation of Velocity Bins

The output sequence of the frequency bins from the FFT is somewhat jumbled and needs unscrambling. This is done as part of forming the velocity bins. Basically, frequency bin powers are read out of the Buffer RAM 414, and then summed together in the accumulator 416 to produce a velocity bin value. This value is then passed to the next process via the Dual Port RAM 418 (or else possibly via a Fast In Fast Out chip). The necessary addressing sequence is controlled by a counter and address mapping ROM (not shown).

The number of additions to be implemented in the accumulator 416 is dependent on the number of frequency bins in each velocity bin. For the bin sizes currently envisaged 710 adds are needed per channel per 14.6 ms time period, making a total rate of 48 x 710 per 14.6 ms = 2.4 M additions per second or 420 ns per addition. This is easily achieved with a single adder.

The number of velocity bins produced at the end of this process are 80 (= 2x8 (from the 2x256 point FFT processing) + 8x8 (from the 8x64 point FFT processing) per channel per 14.6 ms period, making a total of 264 k words per second, or one word per 3.8 $\mu$s.

### 4.5 Downsampling, Noise Estimation, Thresholding

Because of the requirement for downsampling, the procedure described in this section is structurally quite complex; it is therefore implemented in the preferred embodiment in a

programmable process.

The time taken to receive 512 signal samples on each channel is 14.6 ms (=512/35000). The following data are output from the accumulator (velocity bin generator) 416:

(a) For each of the 8 lowest velocity bins: 2 samples per channel = 2 x 8 x 48 = 768 samples, and

(b) For each of the 8 upper velocity bins: 8 samples per channel = 8 x 8 x 48 = 3072 samples.

The downsampling procedure is as follows. For each velocity bin of each channel, the power data is downsampled (in the accumulator 416) by adding samples at successive time periods. As described above, the purpose of the downsampling is to render the data velocity independent. In the preferred embodiment, the downsampling factors vary between 2 and 8.

When downsampling is complete, the new (downsampled) power estimate is compared with a noise threshold based on delayed low-pass filtered noise. If the power is above the threshold, this fact is recorded, for instance as a binary bit in a word, for later processing by the pattern matcher PROM 424. The noise is estimated as a long time estimate of received power appropriately delayed to stop the missile detections on approach de-sensitising the receiver. The noise threshold is updated periodically (say every 8 seconds).

The noise estimation and noise thresholding procedure is described below in terms of suitable computer program steps (written in "pseudo-code").

```
Comment: The following must happen once every 14.6 ms
do chan = 1, 48
```

```
   do vbin = 1, 16
Comment: since the "do vbin" loop is a time-critical loop,
it is preferably written in in-line code (that is, with no
jumps, conditional statements or the like)
         do samp = 1, nsamp(vbin)
Comment: nsamp is either 2 or 8 (corresponding to the 2x256
or the 8x64 FFT processing respectively)
            fetch input_sample
            downsum(chan, vbin) += input_sample

            increment down_counter(chan, vbin)

            if(down_counter>=downsample_factor(vbin)) then

Comment: a new downsampled value is now available

Comment: update sum of powers for noise estimation
                  power = downsum(chan, vbin)
                  powersum(chan, vbin) += power

Comment: update noise threshold estimate
                  threshold(chan, vbin) += delta(chan, vbin)

Comment: compare new value with current threshold
Comment: "detect" is like a delay line stored in a 16 bit
word
                  shift detect(chan, vbin) one place left
                  if (power > threshold(chan, vbin)) then
                     set bottom bit of detect(chan, vbin)
                  endif
                  output detect(chan, vbin) to pattern
                  matcher

Comment: if necessary, update noise estimation delay line
                  increment block_count (chan, vbin)
                  if(block_count(chan,vbin) >=
                  block_len(vbin)) then
```

```
Comment: shift delay line (or change pointer to circular
buffer)
                        do i = delay_len(vbin), 2, -1
                           delay(chan, vbin, i) = delay(chan,
                           vbin, i-1)
                        enddo

Comment: calculate noise threshold based on last block and
enter into delay line
                        delay(chan, vbin, 1) =
                        power_sum(chan, vbin)/block_len(vbin)
                        * thres_mult(vbin) + thresh_add(vbin)

Comment: compute threshold increment
                        delta(chan, vbin) =
                        (delay(chan, vbin, delay_len(vbin)) -
                        threshold(chan,    vbin)    )    /
                        block_len(vbin)

Comment: zero the summing variable and the counter
                        power_sum(chan, vbin) = 0
                        block_count(chan, vbin) = 0

                    endif
                    down_counter = 0
                    down_sum(chan, vbin) = 0
                endif
            enddo
        enddo
enddo
```

The above computer program steps describe the relevant procedure to be carried out. Of course, it is possible to carry the procedure out in different ways; the fastest way to implement it may be to put the channel counters as the innermost loops.

### 4.6 Pattern Matching

Pattern matching was described in some detail in Section 3 above. It is implemented with a small amount of custom logic (large AND gates, priority encoders, and so on) and a single PROM 424. The custom logic would probably be put into a PAL or Xylinx (trade mark) chip.

The pattern matcher is fed with 6 words (one for each range gate) (16 or 32 bit) for each receiver and each velocity bin at the downsampled rate. For the fastest velocity bins, the downsampled rate is 35000/64 per channel, and thus there are 35000/64 x 48 words per second to evaluate, making 26,300 per second. Over all velocity bins the total is 152,000 per second.

Since each pattern matching operation produces two results per receiver (one approach, one recede), the output from the pattern matcher is 152000/6 x 2 = 51 k results per second.

Of course, it is also possible to use a more programmable rather than a hardware approach. In this case, a score for each receiver is generated from the number of consistent range gates detecting the missile. For instance, if for a receiver 4 range gates detect the missile consistently but there is one spurious event, one might generate a score from:-

Score = 4 - 1xFalse Alarm Penalty

The scores for each receiver are then assessed by the receiver amalgamation process.

### 4.7 Receiver Amalgamation

Receiver amalgamation is accomplished using the

programmable processor 426. From the above stage, new results are arriving at the rate of one per 20 $\mu s$. These would arrive in batches of 16 related to particular velocity bins. The first task of the receiver amalgamation processor 426 would be to correlate the results across the receivers. By this means the majority of the data is soon discarded. In a preferred embodiment, this first step takes place as an interrupt driven process. A processor such as the 680x0 would have up to about 100 instructions per sample available to process the incoming data.

Any remaining work involved in correlating across velocity bins and between approach and recede events is then carried out as a background process. The process would be to identify engagements when consistent activity at a particular velocity bin is seen at a set of receivers. Typically this would occur if an engagement score threshold was exceeded at more than one receiver. A typical engagement score threshold would be 3 range gates detecting in the same velocity bin for 2 receivers.

It will be understood that the present invention has been described above purely by way of example, and modifications of detail can be made within the scope of the invention.

CLAIMS

1. Apparatus for determining a displacement characteristic of an object, comprising

means for transmitting, at a given transmission time, a probe signal towards the object;

means for receiving the probe signal returned by the object;

means for generating a detection timing signal at a delay after the transmission time, corresponding to a selected range for the object;

first detecting means, coupled to the receiving means and responsive to the timing signal, for detecting the returned probe signal occurring at the delay of the timing signal; and

second detecting means for detecting the relative timing of the detection timing signal and of a signal having a predetermined timing with respect to the transmission time;

whereby the object displacement characteristic can be determined from the relative timing of these two signals.

2. Apparatus according to Claim 1 wherein the transmitting means is adapted to transmit the probe signal at regularly repeated transmission times, at a given repetition frequency, and the second detecting means is adapted to sample the signal of predetermined timing at a sampling frequency lower than the repetition frequency.

3. Apparatus according to Claim 2 wherein the sampling frequency is less than 100 millionths of the repetition frequency, preferably lees than 20 or even 5 millionths.

4. Apparatus according to Claim 2 or 3 including two oscillators for timing the operation of the transmitting and second detecting means so that the repetition frequency

is timed by one oscillator and the sampling frequency is timed by the beat frequency between the two oscillators.

5. Apparatus according to Claim 1, 2, 3 or 4 wherein the transmitting means is adapted to transmit the probe signal not only to the object but also via a path of fixed length, which does not include the object, through the ambient medium to the receiving means, and the second detecting means is adapted to detect the fixed path length signal as the signal having a predetermined timing with respect to the transmission time.

6. Apparatus according to any of the preceding claims including splitter means for splitting the signal received by the receiving means to both the first and the second detecting means.

7. Apparatus according to any of the preceding claims including means for combining the signal having a predetermined timing and the detection timing signal, and for passing the combined signal to the second detecting means.

8. Apparatus according to any of the preceding claims including means for producing a signal representative of the status of the apparatus in dependence on the output of the second detecting means.

9. Apparatus according to any of the preceding claims wherein the generating means is adapted to generate a plurality of detection timing signals, and the second detecting means is adapted to detect the timing of each of the detection timing signals relative to the signal having a predetermined timing.

10. Apparatus according to any of the preceding claims including means for determining a measure of the selected

range from the relative timing of the signal having a predetermined timing and the detection timing signal.

11. A method of determining a displacement characteristic of an object, comprising

transmitting, at a given transmission time, a probe signal towards the object;

receiving the probe signal returned by the object;

generating a detection timing signal at a delay after the transmission time, corresponding to a selected range for the object;

a first detecting step wherein the returned probe signal occurring at the delay of the timing signal is detected; and

a second detecting step wherein the relative timing of the detection timing signal and of a signal having a predetermined timing with respect to the transmission time is detected;

whereby the object displacement characteristic can be determined from the relative timing of these two signals.

12. A method according to Claim 11 wherein the probe signal is transmitted at regularly repeated transmission times, at a given repetition frequency, and the signal of predetermined timing is sampled at a sampling frequency lower than the repetition frequency.

13. A method according to Claim 12 wherein the sampling frequency is less than 100 millionths of the repetition frequency, preferably lees than 20 or even 5 millionths.

14. A method according to any of Claims 11 to 13 wherein the probe signal is transmitted not only to the object but also via a path of fixed length, which does not include the object, through the ambient medium, and the fixed path length signal is detected in the second detecting step as the signal having a predetermined timing with respect to the transmission time.

15. A method according to any of Claims 11 to 14 wherein a plurality of detection timing signals are generated, and the timing of each of these signals relative to the signal having a predetermined timing is detected in the second detecting step.

16. A method according to any of Claims 11 to 15 wherein a measure of the selected range is determined from the relative timing of the signal having a predetermined timing and the detection timing signal.

17. Apparatus for transmitting data, comprising

input means for receiving a plurality of data samples;

means for evaluating a respective block data value characteristic of each of a plurality of data blocks, each data block comprising a plurality of data samples; and

means for transmitting the respective data value for each block.

18. Apparatus according to Claim 17, wherein the evaluating means is adapted to evaluate individual data values representative of particular data samples in each block, and the transmitting means is adapted to transmit said individual values.

19. Apparatus according to Claim 18, wherein the evaluating means is adapted to evaluate the block and individual data values respectively as an exponent which is constant for each block and a plurality of mantissas which are variable within each block.

20. Apparatus according to Claim 18 or 19, wherein the evaluating means is adapted to evaluate the individual data values as taking as possible values the value zero as well as at least one other value.

21. Apparatus according to Claim 18, 19 or 20, wherein the evaluating means is adapted to evaluate the individual data values as taking one of an odd number of possible values.

22. Apparatus according to any of Claims 18 to 21, wherein the transmitting means is adapted to transmit the individual data values as *n* bit words, each word representing *m* individual data values, the number of possible values for the individual data values taken to the power *m* being no less than 25 % lower than, preferably no less than 10 % lower than, and no greater than, two taken to the nearest power of *n*.

23. Apparatus according to Claim 22, wherein *m* is 3, and said number of possible values is either 3 or 5.

24. Apparatus according to any of Claims 18 to 23, wherein the evaluating means is adapted to evaluate the individual data values in dependence on the difference between data samples or samples.

25. Apparatus according to Claim 24, wherein the transmitting means is adapted to transmit at least one further data value characteristic of the absolute value of a given data sample or samples.

26. Apparatus for receiving data, comprising

means for receiving the data in the form of a plurality of block data values, each block data value being characteristic of a respective data block, the block comprising a plurality of data samples;

means for evaluating the data samples in dependence on the block data values; and

means for outputting the data samples.

27. Apparatus according to Claim 26, wherein the receiving means is adapted to receive individual data values representative of particular data samples in each block, and the evaluating means is adapted to evaluate the data samples in further dependence on the individual data values.

28. Apparatus according to Claim 27, wherein the evaluating means is adapted to evaluate the data samples in dependence on block and individual data values which are respectively an exponent which is constant for each block and a plurality of mantissas which are variable within each block.

29. Apparatus according to Claim 27 or 28, wherein the evaluating means is adapted to evaluate the data samples in dependence on individual data values which take as possible values the value zero as well as at least one other value.

30. Apparatus according to Claim 27, 28 or 29, wherein the evaluating means is adapted to evaluate the data samples in dependence on individual data values which take one of an odd number of possible values.

31. Apparatus according to any of Claims 27 to 30, wherein the receiving means is adapted to receive data as *n* bit words, each word representing *m* individual data values, the number of possible values for the individual values taken to the power *m* being no less than 25 % lower than, preferably no less than 10 % lower than, and no greater than, two taken to the nearest power of *n*, and is further adapted to convert each received word into the *m* individual data values.

32. Apparatus according to any of Claims 27 to 31, wherein the evaluating means is adapted to evaluate the data samples on the basis that the individual data values

have been evaluated in dependence on the difference between data samples.

33. Apparatus according to Claim 32, wherein the receiving means is adapted to receive at least one further data value characteristic of the absolute value of a given data sample or samples.

34. Data transfer apparatus comprising apparatus according to any of Claims 17 to 25 and apparatus according to any of Claims 26 to 33.

35. A method of transmitting data, comprising
receiving a plurality of data samples;
evaluating a respective block data value characteristic of each of a plurality of data blocks, each data block comprising a plurality of data samples; and
transmitting the respective data value for each block.

36. A method according to Claim 35, wherein individual data values representative of particular data samples in each block are evaluated, and said individual values are transmitted.

37. A method according to Claim 36, wherein the block and individual data values are evaluated respectively as an exponent which is constant for each block and a plurality of mantissas which are variable within each block.

38. A method according to Claim 36 or 37, wherein the individual data values are evaluated as taking as possible values the value zero as well as at least one other value.

39. A method according to Claim 36, 37 or 38, wherein the individual data values are evaluated as taking one of an odd number of possible values.

40. A method according to any of Claims 36 to 39, wherein the individual data values are transmitted as *n* bit words, each word representing *m* individual data values, the number of possible values for the individual data values taken to the power *m* being no less than 25 % lower than, preferably no less than 10 % lower than, and no greater than, two taken to the nearest power of *n*.

41. A method according to Claim 40, wherein *m* is 3, and said number of possible values is either 3 or 5.

42. A method according to any of Claims 36 to 41, wherein the individual data values are evaluated in dependence on the difference between data samples.

43. A method of receiving data, comprising

receiving the data in the form of a plurality of block data values, each block data value being characteristic of a respective data block, the block comprising a plurality of data samples;

evaluating the data samples in dependence on the block data values; and

outputting the data samples.

44. A method according to Claim 43, wherein individual data values representative of particular data samples in each block are received, and the data samples are evaluated in further dependence on the individual data values.

45. A method according to Claim 44, wherein the data samples are evaluated in dependence on block and individual data values which are respectively an exponent which is constant for each block and a plurality of mantissas which are variable within each block.

46. A method according to Claim 44 or 45, wherein the data samples are evaluated in dependence on individual data

values which take as possible values the value zero as well as at least one other value.

47. A method according to Claim 44, 45 or 46, wherein the data samples are evaluated in dependence on individual data values which take one of an odd number of possible values.

48. A method according to any of Claims 44 to 47, wherein data is received as *n* bit words, each word representing *m* individual data values, the number of possible values for the individual data values taken to the power *m* being no less than 25 % lower than, preferably no less than 10 % lower than, and no greater than, two taken to the nearest power of *n*, and each received word is converted into the *m* individual data values.

49. A method according to any of Claims 44 to 48, wherein the data samples are evaluated on the basis that the individual data values have been evaluated in dependence on the difference between data samples.

50. Apparatus for assessing the approach of an object to a specified location, comprising

means for detecting the likely presence of the object in a plurality of range regions at specified ranges from said location, and for producing a detection signal for each range region in which the likely presence of the object is detected;

means for determining a measure of the velocity of the object; and

means for assessing the approach of the object in dependence on whether the velocity measure is consistent with the evolution pattern of the detection signals.

51. Apparatus according to Claim 50, wherein the determining means is adapted to determine the velocity measure by sensing the velocity of the object in a

plurality of velocity bands.

52. Apparatus according to Claim 51, wherein the detecting means is adapted to produce detection signals for each velocity band, and including means for adjusting the evolution patterns for the velocity bands so that they are substantially independent of velocity.

53. Apparatus according to Claim 51 or 52, wherein the determining means is such that the velocity bands overlap one another.

54. Apparatus according to any of Claims 51 to 53, wherein the detecting means is adapted to detect the likely presence of the object separately at each velocity band, and the assessing means is adapted to assess the approach of the object in dependence separately on the respective evolution pattern of the detection signals at each velocity band.

55. Apparatus according to any of Claims 50 to 54, wherein the assessing means is adapted to assess the approach of the object in dependence on whether the evolution pattern falls between two extremes of allowability.

56. Apparatus according to any of Claims 50 to 55, wherein the assessing means is adapted to assess the approach of the object in dependence on whether the evolution pattern approximates to a hyperbolic function.

57. Apparatus according to any of Claims 50 to 56, wherein the detecting means comprises a plurality of individual detecting means, preferably at separate locations, and the assessing means is adapted to assess the approach of the object in dependence on the respective evolution pattern of the detection signals for each

individual detecting means.

58. Apparatus according to any of Claims 50 to 57, including means for generating an estimate of background noise, and wherein the detecting means is adapted to produce the detection signal according to whether the detecting means detects the likely presence of the object above a noise threshold which is dependent on the noise estimate.

59. Apparatus according to Claim 58, wherein the generating means is adapted to generate a noise estimate which is time dependent.

60. Apparatus according to Claim 59, wherein the noise threshold is based on a delayed version of the noise estimate.

61. Apparatus according to Claim 59 or 60, wherein the noise threshold is based on a version of the noise estimate averaged over a given duration.

62. Apparatus according to any of Claims 58 to 61, wherein the detecting means is adapted to produce the detection signal according to whether the detecting means detects the likely presence of the object above both of two noise thresholds, one of which is based on the sum of the noise estimate and a first constant, the other of which is based on a second constant times the noise estimate.

63. A method of assessing the approach of an object to a specified location, comprising

detecting the likely presence of the object in a plurality of range regions at specified ranges from said location, and producing a detection signal for each range region in which the likely presence of the object is detected;

determining a measure of the velocity of the object; and

assessing the approach of the object in dependence on whether the velocity measure is consistent with the evolution pattern of the detection signals.

64. A method according to Claim 63, wherein the velocity measure is determined by sensing the velocity of the object in a plurality of velocity bands.

65. A method according to Claim 64, wherein detection signals are produced for each velocity band, and the evolution patterns for the velocity bands are adjusted so that they are substantially independent of velocity.

66. A method according to Claim 64 or 65, wherein the velocity bands overlap one another.

67. A method according to any of Claims 64 to 66, wherein the likely presence of the object is detected separately at each velocity band, and the approach of the object is assessed in dependence separately on the respective evolution pattern of the detection signals at each velocity band.

68. A method according to any of Claims 63 to 67, wherein the approach of the object is assessed in dependence on whether the evolution pattern falls between two extremes of allowability.

69. A method according to any of Claims 63 to 68, wherein the approach of the object is assessed in dependence on whether the evolution pattern approximates to a hyperbolic function.

70. A method according to any of Claims 63 to 69, wherein a plurality of individual detecting means are provided,

preferably at separate locations, and the approach of the object is assessed in dependence on the respective evolution pattern of the detection signals for each individual detecting means.

71. A method according to any of Claims 63 to 70, wherein an estimate of background noise is generated, and wherein the detection signal is produced according to whether the likely presence of the object is detected above a noise threshold which is dependent on the noise estimate.

72. A method according to Claim 71, wherein a noise estimate is generated which is time dependent.

73. A method according to Claim 72, wherein the noise threshold is based on a delayed version of the noise estimate.

74. A method according to Claim 72 or 73, wherein the noise threshold is based on a version of the noise estimate averaged over a given duration.

75. A method according to any of Claims 71 to 74, wherein the detection signal is produced according to whether the likely presence of the object is detected above both of two noise thresholds, one of which is based on the sum of the noise estimate and a first constant, the other of which is based on a second constant times the noise estimate.

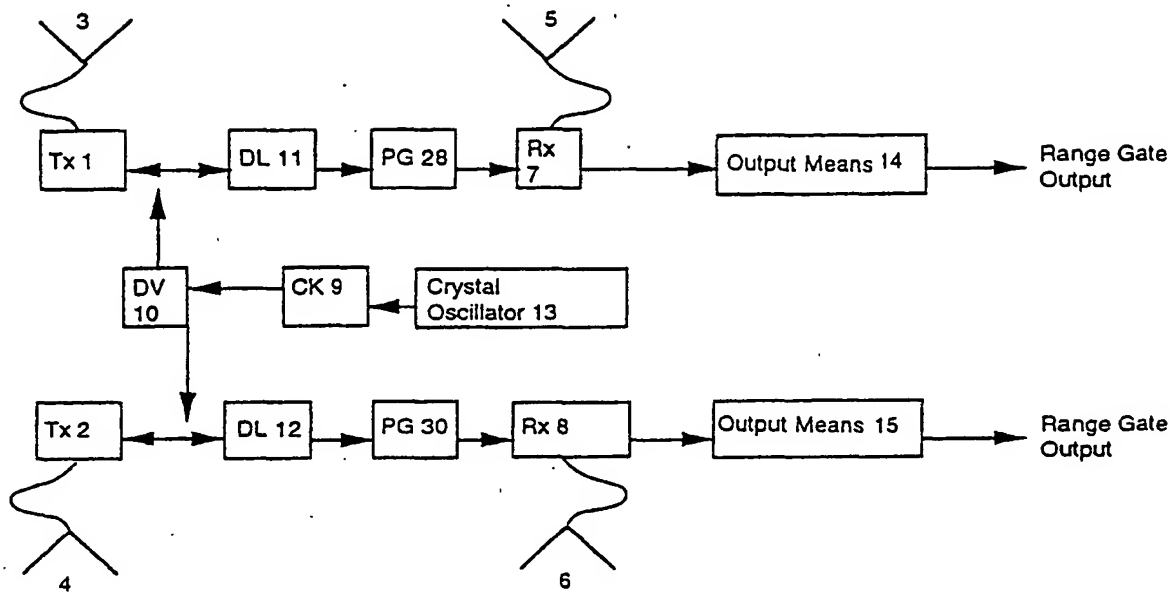
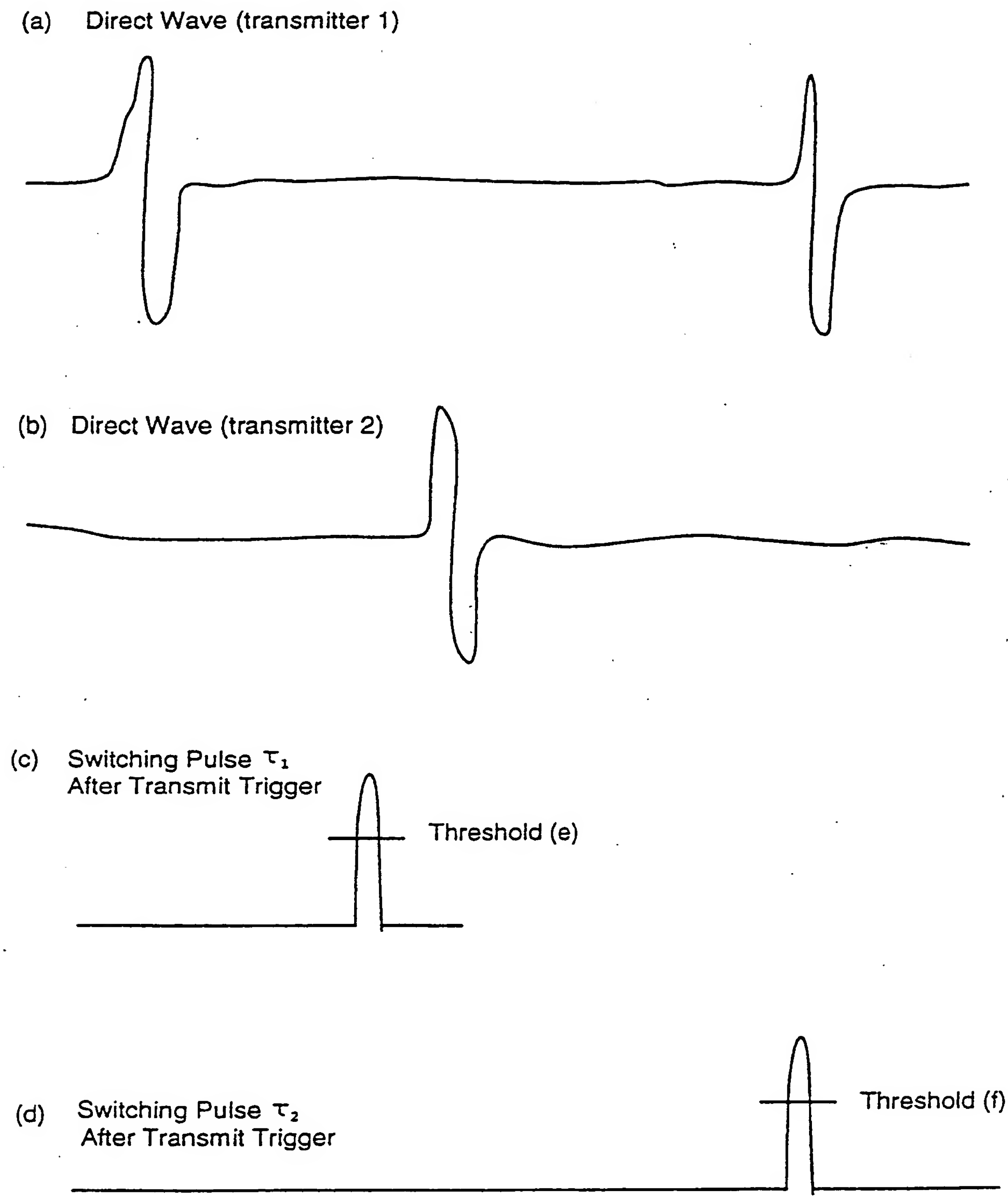



FIGURE 1 (PRIOR ART)


(a) Direct Wave (transmitter 1)
(b) Direct Wave (transmitter 2)
(c) Switching Pulse $\tau_1$ After Transmit Trigger
Threshold (e)
(d) Switching Pulse $\tau_2$ After Transmit Trigger
Threshold (f)

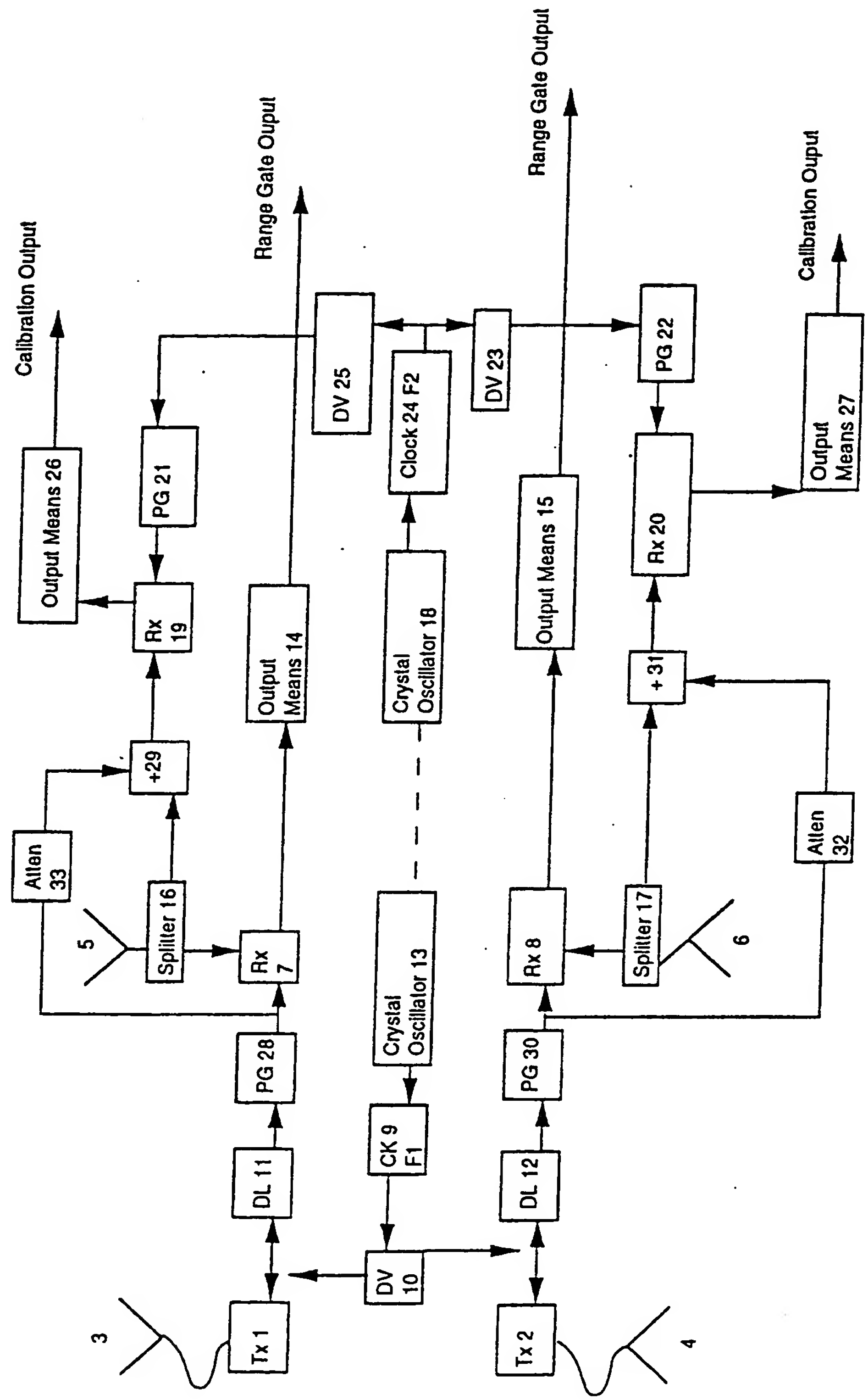

Calibration Output
Range Gate Ouput
Range Gate Output
Calibration Ouput
Output Means 26
PG 21
DV 25
Clock 24 F2
DV 23
PG 22
Output Means 27
Rx 19
Output Means 14
Crystal Oscillator 18
Output Means 15
Rx 20
+29
+ 31
Atten 33
Splitter 16
Rx 7
Crystal Oscillator 13
Rx 8
Splitter 17
Atten 32
5
6
PG 28
CK 9 F1
PG 30
DL 11
DL 12
DV 10
Tx 1
Tx 2
3
4

FIGURE 3

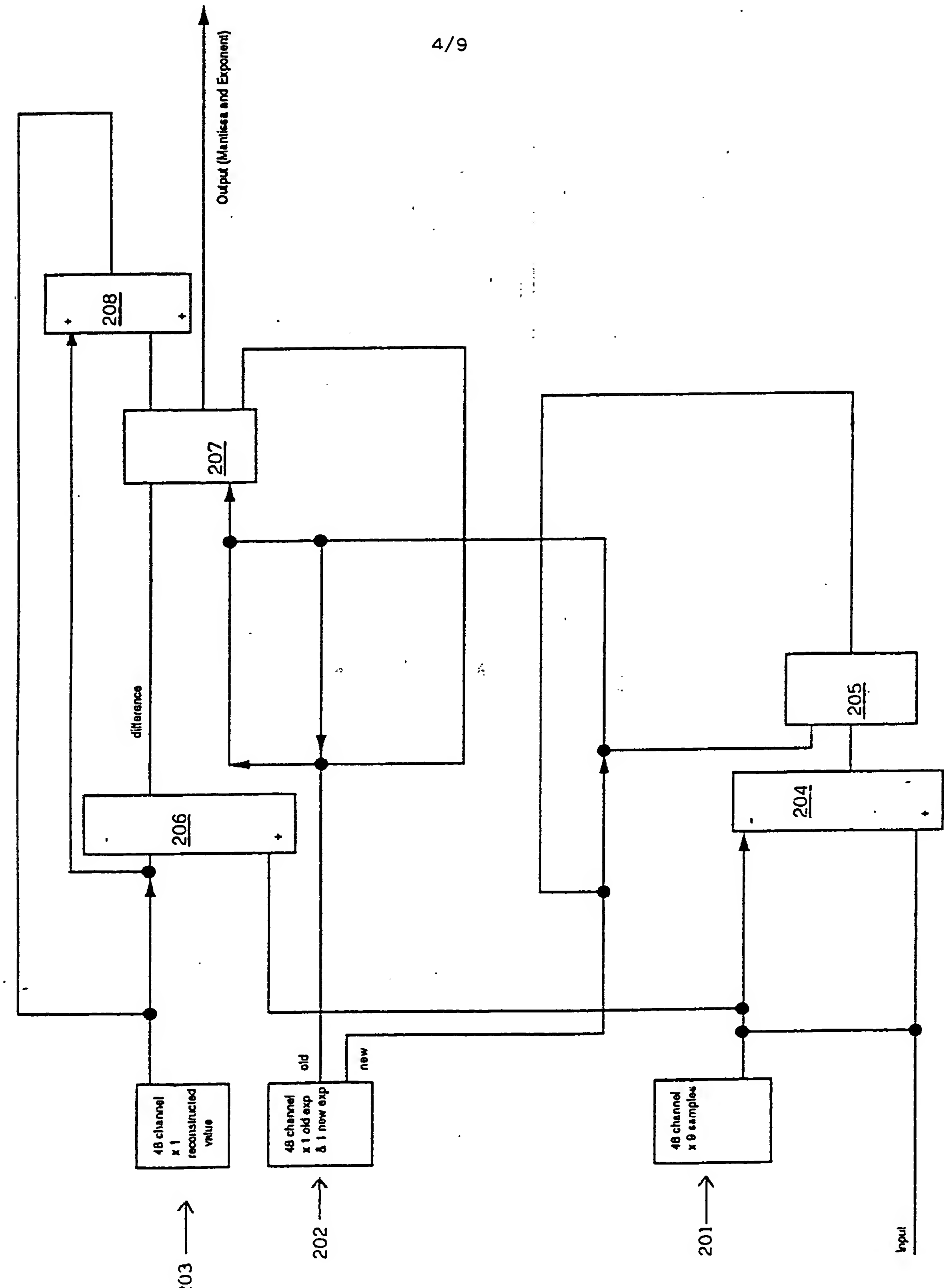
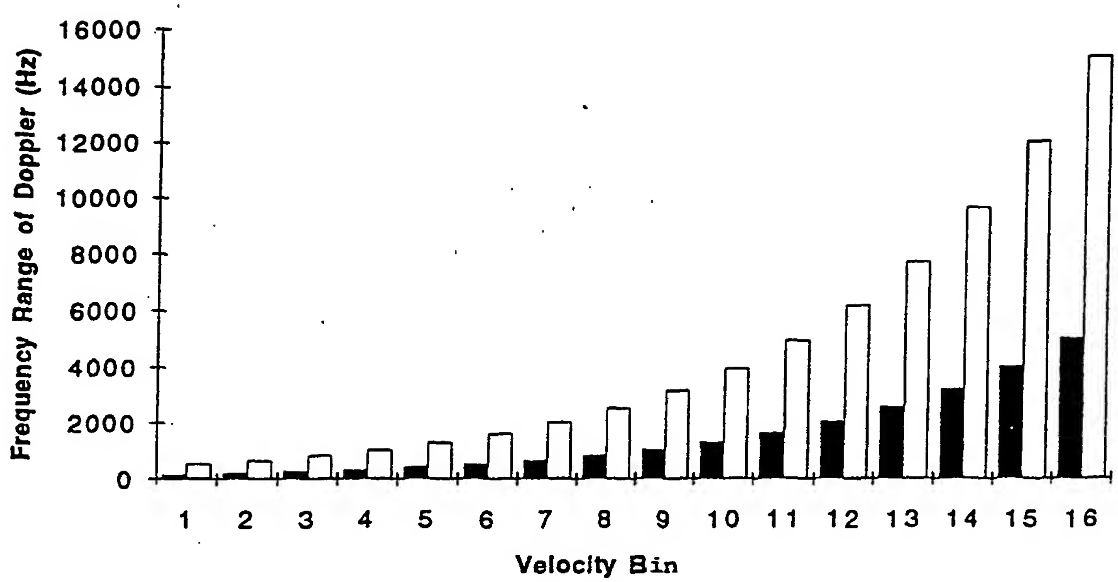

Output (Mantissa and Exponent)
208
207
206
205
204
difference
old
new
48 channel x 1 reconstructed value
48 channel x 1 old exp & 1 new exp
48 channel x 9 samples
203
202
201
Input

FIGURE 4



16000
14000
12000
10000
8000
6000
4000
2000
0
Frequency Range of Doppler (Hz)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Velocity Bin


FIGURE 5

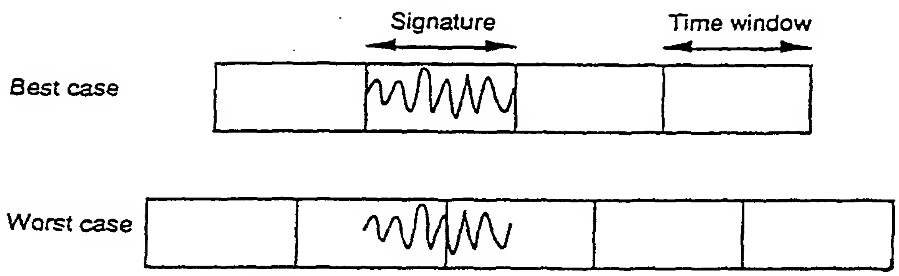



FIGURE 6

| | |
|---|---|
| outer gate | 0000000100000000 |
| next gate | 0000000010000000 |
| next gate | 0000000001000000 |
| next gate | 0000000000100000 |
| next gate | 0000000000010000 |
| inner gate | 0000000000001000 |
| | |
| outer gate | 0000100000000000 |
| next gate | 0000001000000000 |
| next gate | 0000000010000000 |
| next gate | 0000000000100000 |
| next gate | 0000000000001000 |
| inner gate | 0000000000000010 |

FIGURE 9

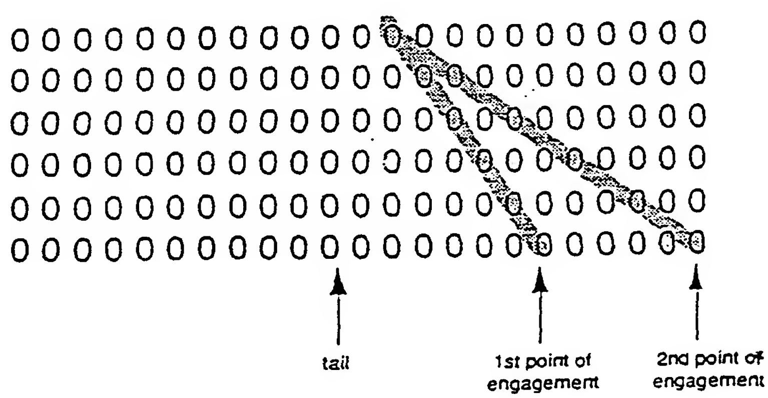



FIGURE 10

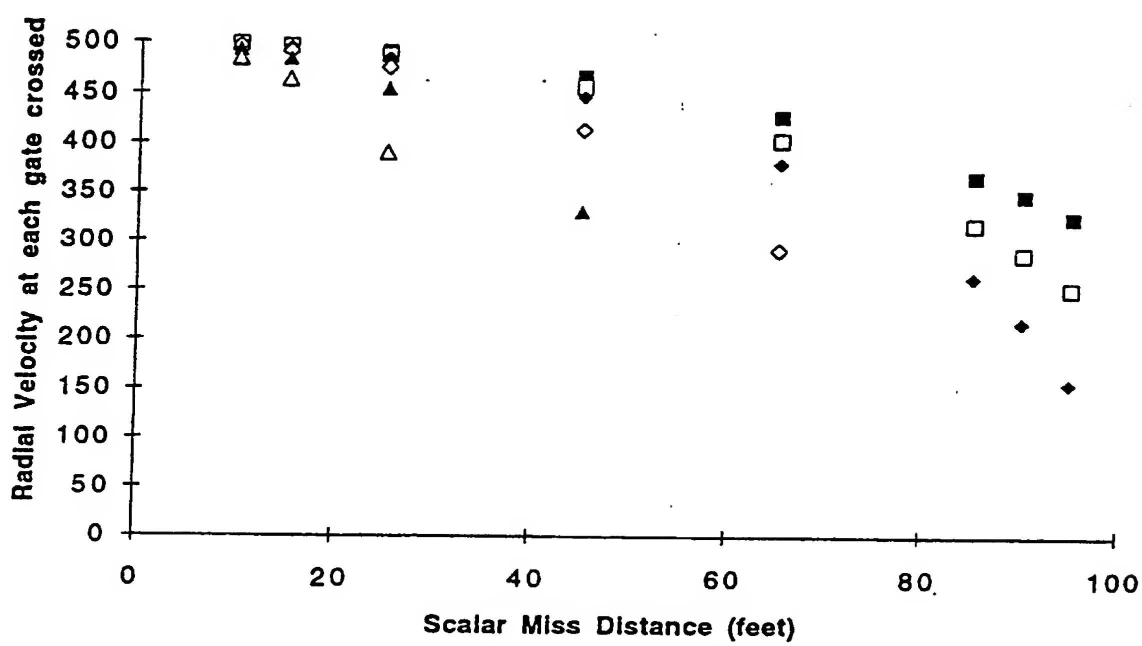

Radial Velocity at each gate crossed
500
450
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
Scalar Miss Distance (feet)

FIGURE 7

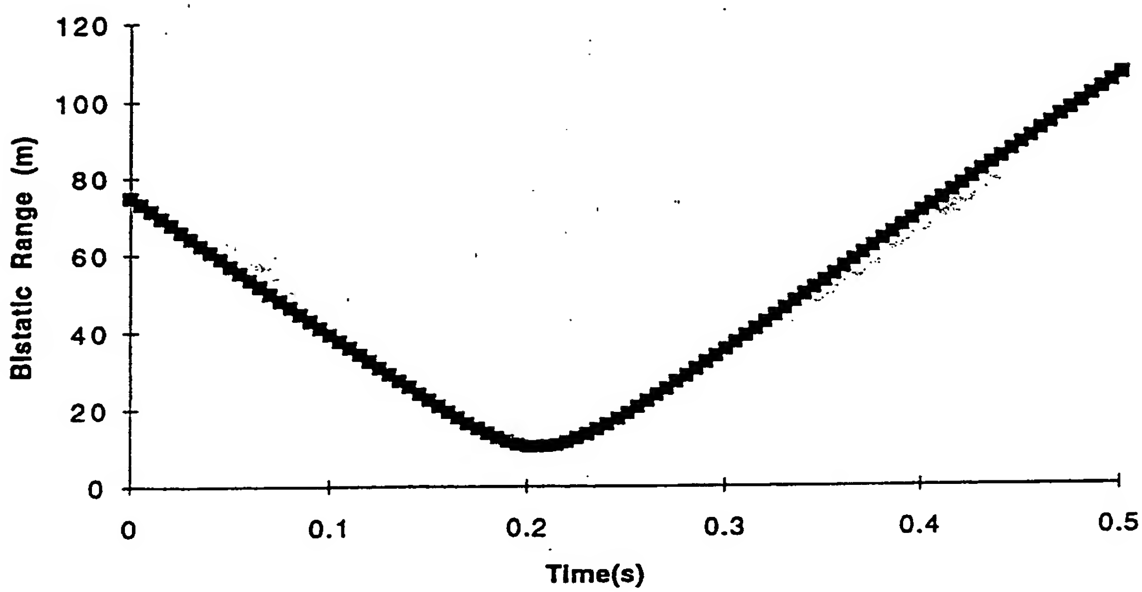



FIGURE 8

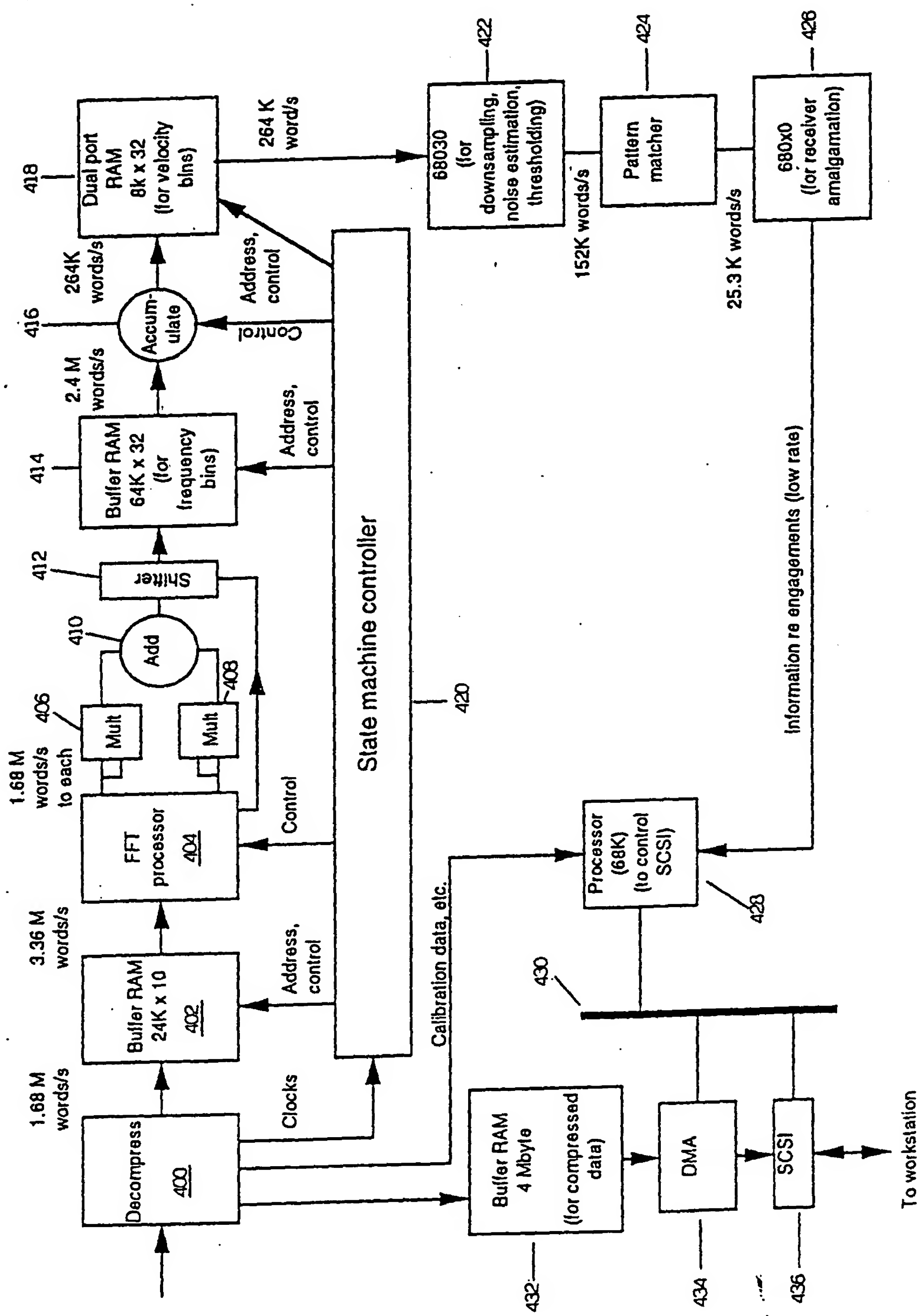

Decompress
400
1.68 M words/s
Buffer RAM 24K x 10
402
3.36 M words/s
FFT processor
404
1.68 M words/s to each
Mult
406
Mult
408
Add
410
Shifter
412
Buffer RAM 64K x 32 (for frequency bins)
414
2.4 M words/s
Accum-ulate
416
264K words/s
Dual port RAM 8k x 32 (for velocity bins)
418
264 K word/s
Clocks
Address, control
Control
Address, control
Control
Address, control
State machine controller
420
68030 (for downsampling, noise estimation, thresholding)
422
152K words/s
Pattern matcher
424
25.3 K words/s
680x0 (for receiver amalgamation)
426
Information re engagements (low rate)
Calibration data, etc.
Processor (68K) (to control SCSI)
428
430
Buffer RAM 4 Mbyte (for compressed data)
432
DMA
434
SCSI
436
To workstation

FIGURE 11

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| | | |
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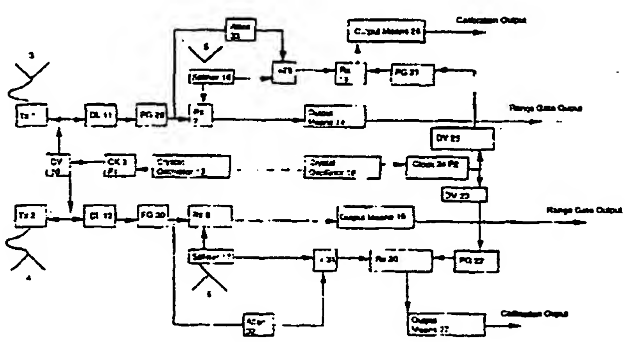
(54) Title: APPARATUS AND METHOD FOR DISPLACEMENT DETERMINATION, DATA TRANSFER AND ASSESSMENT



(57) Abstract

Apparatus for determining a displacement characteristic of an object comprises means (Tx1, Tx2, 3, 4) for transmitting, at a given transmission time, a probe signal towards the object; means (5, 6) for receiving the probe signal returned by the object; means (DL11, DL12, PG28, PG30) for generating a detection timing signal at a delay after the transmission time, corresponding to a selected range for the object; first detecting means (Rx7, Rx8), coupled to the receiving means and responsive to the timing signal, for detecting the returned probe signal occurring at the delay of the timing signal; and second detecting means (Rx19, Rx20) for detecting the relative timing of the detection timing signal and of a signal having a predetermined timing with respect to the transmission time; whereby a measure of the range of the object can be determined from the relative timing of these two signals, from which range measure the object displacement characteristic can be determined. Apparatus for transmitting and receiving data is also disclosed, as further is apparatus for assessing the approach of an object to a specified location. Analogous methods are also disclosed.

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# INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/00738

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 5 G01S7/40 G01S13/18 G01S7/00 G01S13/58 H03M7/30
F41J5/12

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G01S H03M F41J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | CH,A,652 832 (SIEMENS) 29 November 1985 | 1,5,7, 10,11, 14,16 |
| Y | see the whole document | 2,12 |
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 9 November 1994 | 17. 11. 94 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. ( +31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: ( +31-70) 340-3016 | Zaccà, F |

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International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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| X | EP,A,0 293 533 (FREDERIKSEN & SHU LABORATORIES) 7 December 1988<br>see abstract | 17-19, 26-28, 35-37, 43-45 |
| X | JOURNAL OF THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS, vol.55, no.7/8, August 1985, LONDON GB pages 247 - 252<br>J. ROBINSON 'An L.S.I.-based p.c.m. processor for high-quality sound transmission'<br>see page 247 | 17,26, 35,43 |
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| Y | see page 574 | 24,32, 42,49 |
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# INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB94/00738

**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. claims 1-16: Displacement Characteristic Determining Apparatus and Method
2. claims 17-49: Data Transmission and Reception Apparatus and Method
3. claims 50-75: Assessment Apparatus and Method

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 94/00738

| Patent document cited in search report | Publication date | Patent family member(s) | | Publication date |
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